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(NASA-CR-148496) SEASAT ECONOMIC ASSESSMENT. VOLUME 3: OFFSHORE OIL AND NATURAL GAS INDUSTRY CASE STUDY AND GENERALIZATION Final Report, Feb. 1974 - Aug. 1975 (ECON, Inc., Princeton, N.J.) G3/43

N76-28616
HC $4.00

Unclas
15358

VOLUME III

SEASAT ECONOMIC ASSESSMENT

OFFSHORE OIL AND NATURAL GAS INDUSTRY CASE STUDY AND GENERALIZATION

ECON INCORPORATED

Report No. 75-125-3B
NINE HUNDRED STATE ROAD
PRINCETON, NEW JERSEY 08540
609 924-8778

FINAL

VOLUME III

SEASAT ECONOMIC ASSESSMENT

OFFSHORE OIL AND NATURAL GAS INDUSTRY

CASE STUDY AND GENERALIZATION

Prepared for

National Aeronautics and Space Administration
Washington, D.C.

Contract No. NASW-2558

August 31, 1975

NOTE OF TRANSMITTAL

The SEASAT Economic Assessment was performed for the Special Programs Division, Office of Applications, National Aeronautics and Space Administration, under Contract NASW-2558. The work described in this report began in February 1974 and was completed in August 1975.

The economic studies were performed by a team consisting of Battelle Memorial Institute, the Canada Centre for Remote Sensing, ECON, Inc., the Jet Propulsion Laboratory and Ocean Data Systems, Inc. ECON, Inc. was responsible for the development of the models used in the generalization of the results.

This volume presents case studies and their generalizations concerning the economic benefits of improved ocean condition, weather and ice forecasts to the exploration, development and production of oil and natural gas in the offshore regions.

The case studies were performed by Battelle Memorial Institute, under the direction of Mr. C.W. Hamilton. Mr. K. Kicks of ECON, Inc. performed the generalization of the case study results. An independent study of offshore operations, performed by Dr. A.K. McQuillan of the Canada Centre for Remote Sensing, is included as a part of the generalization.

The SEASAT Users Working Group (now Ocean Dynamics Subcommittee), chaired by Dr. J. Apel of the National Oceanographic and Atmospheric Administration, served as a valuable source of information and a forum for the review of these studies. Mr. S.W. McCandless, the SEASAT Program Manager, coordinated the activities of the many organizations that participated in these studies into the effective team that obtained the results described in this report.

B.P. Miller

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This report, consisting of ten volumes, represents the results of the SEASAT Economic Assessment, as completed through August 31, 1975. The individual volumes in this report are:

Volume I -	Summary and Conclusions
Volume II -	The SEASAT System Description and Performance
Volume III -	Offshore Oil and Natural Gas Industry - Case Study and Generalization
Volume IV -	Ocean Mining - Case Study and Generalization
Volume V -	Coastal Zones - Case Study and Generalization
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Volume X -	A Program for the Evaluation of Operational SEASAT System Costs.

Each volume is self-contained and fully documents the results in the study area corresponding to the title. Table 1.1 describes the content of each volume to aid readers in the selection of material that is of specific interest.

The SEASAT Economic Assessment began during Fiscal Year 1975. The objectives of the preliminary economic assessment, conducted during Fiscal Year 1975, were to identify the uses and users of the data that could be produced by an operational SEASAT system and to provide preliminary estimates of the benefits produced by the applications of this

Table 1.1: Content and Organization of the Final Report

Volume No.	Title	Content
I	Summary and Conclusions	A summary of benefits and costs, and a statement of the major findings of the assessment.
II	The SEASAT System Description and Performance	A discussion of user requirements, and the system concepts to satisfy these requirements are presented along with a preliminary analysis of the costs of those systems. A description of the plan for the SEASAT data utility studies and a discussion of the preliminary results of the simulation experiments conducted with the objective of quantifying the effects of SEASAT data on numerical forecasting.
III	Offshore Oil and Natural Gas Industry-Case Study and Generalization	The results of case studies which investigate the effects of forecast accuracy on offshore operations in the North Sea, the Celtic Sea, and the Gulf of Mexico are reported. A methodology for generalizing the results to other geographic regions of offshore oil and natural gas exploration and development is described along with an estimate of the world-wide benefits.
IV	Ocean Mining - Case Study and Generalization	The results of a study of the weather sensitive features of the near shore and deep water ocean mining industries are described. Problems with the evaluation of economic benefits for the deep water ocean mining industry are attributed to the relative immaturity and highly proprietary nature of the industry.

Table 1.1· Content and Organization of the Final Report
(continued)

Volume No.	Title	Content
V	Coastal Zones - Case Study and Generalization	The study and generalization deal with the economic losses sustained in the U.S coastal zones for the purpose of quantitatively establishing economic benefits as a consequence of improving the predictive quality of destructive phenomena in U.S. coastal zones. Improved prediction of hurricane landfall and improved experimental knowledge of hurricane seeding are discussed.
VI	Arctic Operations - Case Study and Generalization	The hypothetical development and transportation of Arctic oil and other resources by ice breaking super tanker to the continental East Coast are discussed. SEASAT data will contribute to a more effective transportation operation through the Arctic ice by reducing transportation costs as a consequence of reduced transit time per voyage.
VII	Marine Transportation-Case Study and Generalization	A discussion of the case studies of the potential use of SEASAT ocean condition data in the improved routing of dry cargo ships and tankers. Resulting forecasts could be useful in routing ships around storms, thereby reducing adverse weather damage, time loss, related operations costs, and occasional catastrophic losses.
VIII	Ocean Fishing - Case Study and Generaliz-ation	The potential application of SEASAT data with regard to ocean fisheries is discussed in this case study. Tracking fish populations, indirect assistance in forecasting expected populations and assistance to fishing fleets in avoiding costs incurred due to adverse weather through improved ocean conditions forecasts were investigated.
IX	Ports and Harbors - Case Study and Generalization	The case study and generalization quantify benefits made possible through improved weather forecasting resulting from the integration of SEASAT data into local weather forecasts. The major source of avoidable economic losses from inadequate weather forecasting data was shown to be dependent on local precipitation forecasting.
X	A Program for the Evaluation of Operational SEASAT System Costs	A discussion of the SATIL 2 Program which was developed to assist in the evaluation of the costs of operational SEASAT system alternatives. SATIL 2 enables the assessment of the effects of operational requirements, reliability, and time-phased costs of alternative approaches.

data.* The preliminary economic assessment identified large potential benefits from the use of SEASAT-produced data in the areas of Arctic operations, marine transportation and offshore oil and natural gas exploration and development.

During Fiscal Year 1976, the effort was directed toward the confirmation of the benefit estimates in the three previously identified major areas of use of SEASAT data, as well as the estimation of benefits in additional application areas. The confirmation of the benefit estimates in the three major areas of application was accomplished by increasing both the extent of user involvement and the depth of each of the studies. Upon completion of this process of estimation, we have concluded that substantial, firm benefits from the use of operational SEASAT data can be obtained in areas that are extensions of current operations such as marine transportation and offshore oil and natural gas exploration and development. Very large potential benefits from the use of SEASAT data are possible in an area of operations that is now in the planning or conceptual stage, namely the transportation of oil, natural gas and other resources by surface ship in the Arctic regions. In this case, the benefits are dependent upon the rate of development of the resources that are believed to be in the Arctic regions, and also dependent upon the choice of surface transportation over pipelines as the means of moving these resources to the lower

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* ECON, Inc. SEASAT Economic Assessment, October 1974.

latitudes. Our studies have also identified that large potential benefits may be possible from the use of SEASAT data in support of ocean fishing operations. However, in this case, the size of the sustainable yield of the ocean remains an unanswered question; thus, a conservative viewpoint concerning the size of the benefit should be adopted until the process of biological replenishment is more completely understood.

With the completion of this second year of the SEASAT Economic Assessment, we conclude that the cumulative gross benefits that may be obtained through the use of data from an operational SEASAT system, to provide improved ocean condition and weather forecasts is in the range of $859 million to $2,709 million ($1975 at a 10 percent discount rate) from civilian activities. These are gross benefits that are attributable exclusively to the use of SEASAT data products and do not include potential benefits from other possible sources of weather and ocean forecasting that may occur in the same period of time. The economic benefits to U.S. military activities from an operational SEASAT system are not included in these estimates. A separate study of U.S. Navy applications has been conducted under the sponsorship of the Navy Environmental Remote Sensing Coordinating and Advisory Committee. The purpose of this Navy study was to determine the stringency of satellite oceanographic measurements necessary to achieve improvements in

military mission effectiveness in areas where benefits are known to exist.* It is currently planned that the Navy will use SEASAT-A data to quantify benefits in military applications areas. A one-time military benefit of approximately $30 million will be obtained by SEASAT-A, by providing a measurement capability in support of the Department of Defense Mapping, Charting and Geodesy Program.

Preliminary estimates have been made of the costs of an operational SEASAT program that would be capable of producing the data needed to obtain these benefits. The hypothetical operational program used to model the costs of an operational SEASAT system includes SEASAT-A, followed by a number of developmental and operational demonstration flights, with full operational capability commencing in 1985. The cost of the operational SEASAT system through 2000 is estimated to be about $753 million ($1975, 0 percent discount rate) which is the equivalent of $272 million ($1975) at a 10 percent discount rate. It should be noted that this cost does not include the costs of the program's unique ground data handling equipment needed to process, disseminate or utilize the information produced from SEASAT data. Figures 1.1 and 1.2 illustrate the net cumulative SEASAT exclusive benefit stream (benefits less costs) as a

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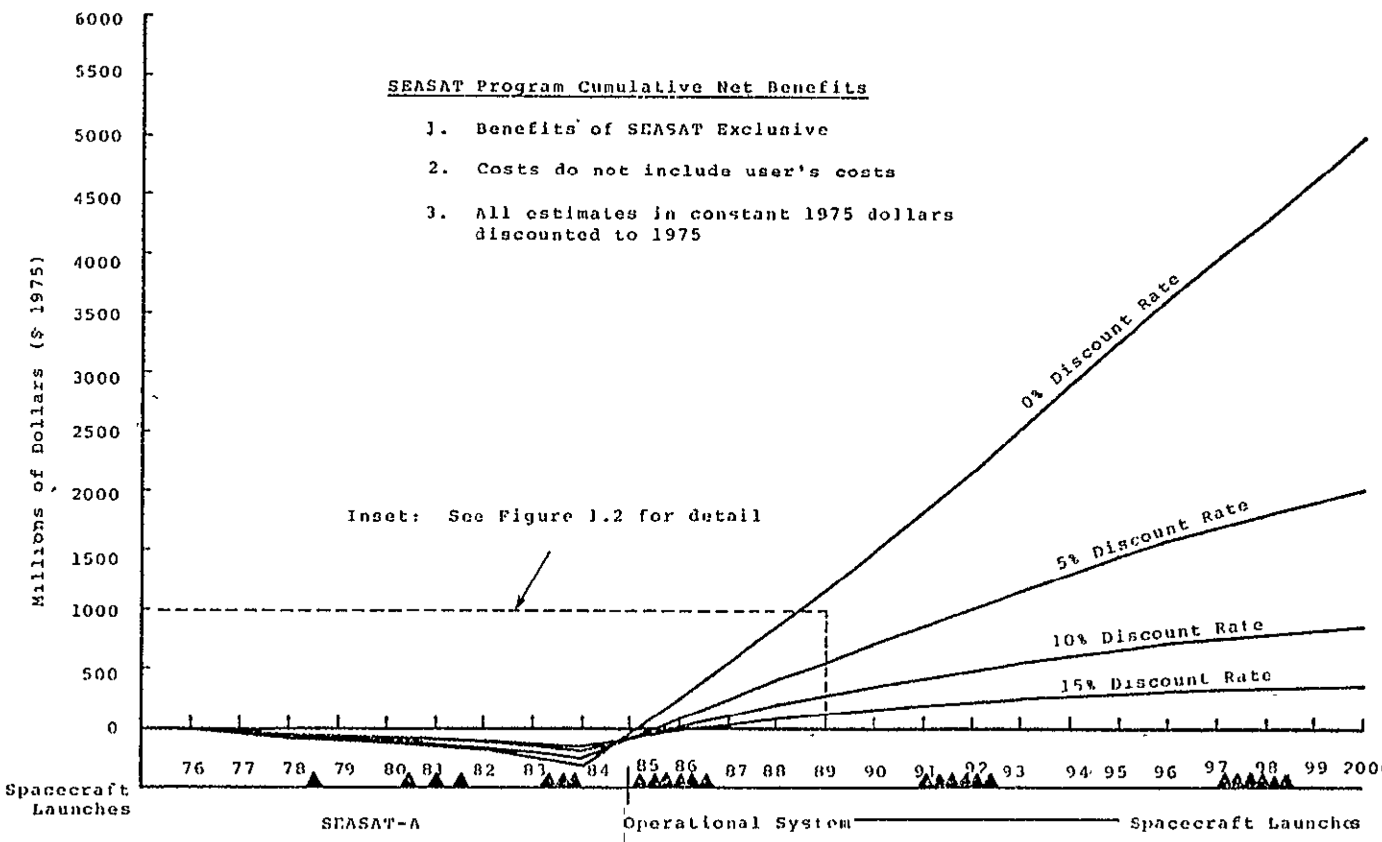
*Navy Remote Sensing Coordinating and Advisory Committee. "Specifications of Stringency of Satellite Oceanographic Measurements for Improvement of Navy Mission Effectiveness." (Draft Report.) May 1975.



Costs*	19	49	78	100	123	151	184	239	307	352	368	373	375	393	437	503	546	566	568	587	629	695	738	753
Benefits*										311	622	933	1244	1555	1937	2319	2701	3083	3465	3847	4229	4611	5375	5757

*Cumulative Costs and Benefits at 0% Discount Rate (millions, $ 1975)

Figure 1.1 SEASAT Program Net Benefits, 1976-2000

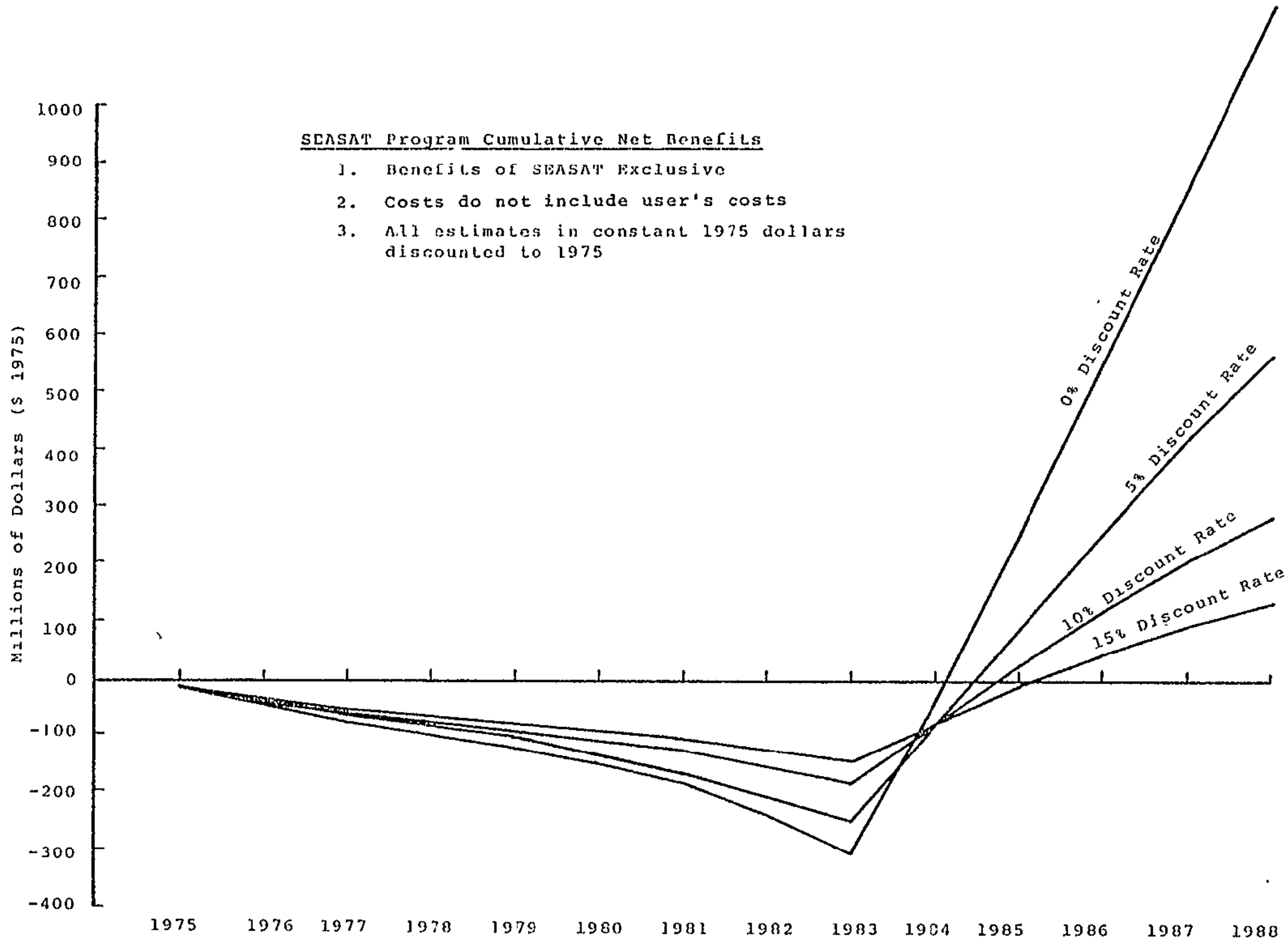


Figure 1.2 SEASAT Program Net Benefits, Inset

function of the discount rate.

This volume presents case studies and their generalization concerning the economic benefits of improved ocean condition, weather and ice forecasts to the exploration, development and production of oil and gas in offshore regions.

2. INTRODUCTION TO THE OFFSHORE OIL AND GAS INDUSTRY CASE STUDY AND GENERALIZATION

The Offshore Oil and Gas Industry explores, prospects and mines gas and oil deposits below the sea. In so doing it pursues a logical sequence of activities, involving specialized equipment and operations, in the context of the sea. The activities require various forms of drilling into the subsea earth's surface from vessels designed to allow the necessary drilling precision, to discover, delineate and develop oil and gas fields so that oil and gas outputs can be produced. Equipment must therefore function effectively in the sea and operations must be as economically efficient as the sea environment will permit, in an attempt to minimize the costs of oil and gas extraction.

SEASAT will be designed and operated to remotely collect global data, without weather constraint, which will serve to improve knowledge, predictive and otherwise, of meteorological and oceanographic conditions at a given place and time for certain durations.

It is assumed that the activities of the offshore oil and gas industry are subject to influences of the environment which produce avoidable economic losses. This implies that with sufficient forewarning these particular economic losses could be reduced or eliminated, provided that alternative forms of the activities can be planned for and undertaken. SEASAT, in its

operational form, will provide data from which forewarning can be made available in a timely and appropriate manner to those involved in offshore oil and gas operations. If it is assumed that alternate forms of activities will occur within these operations then economic savings will result.

The objectives of this case study and its generalization are to quantitatively establish those economic benefits to the offshore oil and gas activities of production platform erection, pipelaying and exploratory drilling, which will result from the use of data provided by an operational SEASAT system. Since the operational SEASAT system will be in orbit after 1985 it is necessary to define the quantities of offshore oil and gas activity beyond 1985.

The procedure used in this study is to quantify economic savings or benefits derived in case studies of specific offshore oil and gas operations. These are then extended or generalized to the worldwide operations of the offshore oil and gas industry. The case studies have treated two separate activities, production platform erection and pipelaying and exploratory drilling. Benefits in the former case study were derived from an actual operation in the southern North Sea supplemented by an actual operation in the Gulf of Mexico. The latter case study was developed from an actual operation in the Celtic Sea. The generalization is developed from a modeling of worldwide offshore oil and gas production from 1985 to 2000, the time horizon for the economic assessment.

The reduction of economic loss (or benefits derived) result from a reduction of avoidable labor costs and from the reduction of accidents both in production platform erection and exploratory drilling. The labor associated benefits arise from a requirement to contract ahead of time in order to assure that labor will be available to perform production or pipelaying tasks. If, when the time for actual performance of these tasks arrives, the weather or sea conditions preclude the work performance, the labor must still be paid, in effect for no work. Such costs could be avoided if the weather and sea conditions expected at the work site could be known with certainty for at least 48 hours ahead. Because such predictions will involve some uncertainty, these costs cannot be completely eliminated, only reduced. It is difficult to estimate conservatively and to strongly substantiate economic benefits that are a consequence of operational accidents that may occur in the future. The basic difficulty lies with accepting the conviction that today's accidents will continue and that procedures will not be introduced which will considerably diminish the economic losses sustained. It is however necessary to bear in mind that the accidents of interest are those that could be avoided if the weather and sea conditions that give rise to them could be predicted ahead of time. That is, it is implied that the accidents of interest are, in reality, those associated with operational activities that must be performed and yet which are known to be susceptible to inclement weather

and sea conditions of certain inclement magnitudes. Thus the occurrence of the accident is a function of the expected ocean conditions to the extent that it would be possible to reschedule the vulnerable activities to periods of less inclement conditions. Knowledge that such inclement conditions will occur will presumably reduce the possibility of these accidents. Today drilling rig operators carefully guard knowledge of their drilling locations, the prevailing weather at these locations, and the times when drilling will occur. Some operators completely ignore weather change predictions; others attempt to directly incorporate into their on-site operations updated facsimile weather charts.* In view of the secrecy that surrounds these operations it may be difficult to determine what data the operators actually need and to implement an accident avoidance system.

Avoidable accidents that are weather and sea condition related do occur in the offshore oil industry. Some of these accidents are quite spectacular in their far-reaching effect on operation downtime. This is a result of equipment damage or loss and the current difficulty of repair and replacement, because of many shortages in the industry. For example, an accident costing the operator $5.4 million or more was described as follows:

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*Offshore, February 1975, p. 76.

> *An operator of a semisubmersible, paying no heed to an approaching storm, loosened an anchor chain to perform an operation. Another chain was dragging. The storm blew in, wrapping one of the anchor chains around the riser and knocking over the BOP stack. As a result, six months of operating time, at more than $30,000 per day, were lost.* *

The blow off preventer (BOP) is a substantial piece of equipment weighing perhaps 100 tons, situated over the well head at sea bottom. The operation of the BOP is automatically controlled to prevent pollution when drilling operations must be shut down under emergency conditions.

In those regions of the world where weather and sea conditions are generally inhospitable yet where oil and gas deposits are apparent, exploration and development capital requirements are such that the pressure to move rapidly into production and recover capital appears to warrant many risks. Political pressure is also a significant force in many regions and safety is not always a cardinal rule.

It is however becoming evident that the influence of weather and sea conditions on the offshore oil and gas industry's costs is initiating integrated regional weather studies and sea bottom studies. One such region is the Indian Ocean. The objectives are to improve design or selection of

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* Offshore, February 1975, p. 100.

the equipment most suited to the characteristics of the operating environment. Additionally weather and sea condition studies are important to the choice of reasonable risk factors for rig and equipment design by which cost savings result because of a clearer understanding of the expected coincidence of environmental phenomena (wave height, wind, current, etc.). It is also clear that weather and sea condition forecasting in the offshore regions is not available from most weather forecasting institutions. These institutions concentrate on forecasting over land where their major responsibility, as governmental services, lies. It is not clear what weather/sea condition data will be most beneficial to operators in different regions of the world, nor what quality of data is required. Some operations, as in the northern North Sea, are most concerned about sudden storms from the North West over the Shetland Islands. In the Indian Ocean it is the sea swells that have a great influence along with the great variation in sea bottom conditions. It seems indisputable that all satellite weather and sea condition data will be of great service to local forecasting organizations operating in the world's regions where offshore oil and gas prospecting will be active. A rigorous determination of the weather and sea condition forecasting dependence of offshore oil and gas activities throughout the world would perhaps enable NASA to attempt a specific satellite design optimized for offshore industry.

Subsequent sections of this chapter summarize the results of the case studies, the modeling of their generalization and the estimation of generalized benefits.

3. SUMMARY AND CONCLUSIONS

3.1 Summary

Case studies have been performed on the offshore oil and gas industry's operations of oil production platform erection, pipelaying and exploratory drilling to determine the influence that weather and sea condition prediction could have on the reduction of avoidable economic losses within these operations.

Each case study was developed from operational data obtained from the industry. Oil production and pipelaying data came from experience in the southern North Sea prior to 1971 and from the Gulf of Mexico off the Louisiana coast in 1972. Exploratory drilling data came from the experience of a drill ship in the Celtic Sea from 1970 to 1974.

The case studies identify avoidable economic losses or benefits associated with the operations as follows:

1. \$0.19 million for each production platform installed
2. \$0.06 million for each mile of pipe laid and trenched
3. \$0.41 million for each jackup drill rig drilling year
4. \$0.54 million for each drillship drilling year
5. \$0.81 million for each semisubmersible drilling year.

The benefits for production platforms and pipelaying arise from reduced contractual costs for nonproductive labor

and from the avoidance of accidents. The benefits require reliable weather and sea condition forecast with a prediction interval of at least 48 hours. The benefits to exploratory drilling arise from the avoidance of accidents during operation and require a highly precise weather and sea state forecast with a maximum prediction interval of 24 hours, since this is the maximum time required to close down exploratory drilling operations.

Accidents are defined in this context as operational activities that must be performed but whose efficiency is dependent on weather and sea conditions. If the predicted weather and sea conditions are such that these activities would be jeopardized it is presumed that they would be postponed and accidents would not occur.

The case study benefits are considered to be realizable assuming the offshore oil industry receives and acts effectively on the weather and sea condition prediction data supplied utilizing data from the operational SEASAT and other sources.

A case study generalization was then performed. The generalization resulted from a simple model which establishes the exploratory drill rig population for the time interval 1975-2000, the expected success of worldwide exploratory drilling in generating oil production, the number of production platforms and the amount of associated pipe that must be laid. The drill rig fleet is assumed to have an ideal composition of 48 percent jackups, 27 percent drillships and 25 percent semi-

submersibles which is matched reasonably to the bathymetric, sea bottom and expected weather and sea conditions in the future world offshore oil exploration and production regions.

The model projects an incremental offshore oil production by 1985 (with respect to a 1975 base) of 15.54 million barrels of oil per day and a total offshore production of 25.54 million barrels of oil per day or about 33 percent of the projected world total oil production. By 2000, the incremental offshore production will be 52.6 million barrels of oil per day for a total oil production of 78.1 million barrels of oil per day or about 60 percent of the then projected world total oil production. The model also projects a rig fleet that will grow from 300 vessels in 1975 to 700 vessels in 1985 which will then decline as a result of concentration on production at the rate of 10 per annum due to vessel retirements and losses at sea.

The production between 1985 and 2000 will require the fabrication and installation of 526 production platforms each producing 0.1 million barrels of oil per day. To sustain this production, between 65,940 and 89,893 miles of pipe must be laid. Between 1975 and 2000 the industry capital requirements are estimated to be $560 billion. To achieve these rates of production and to maintain a 30:1 ratio between reserves and production, approximately 855 billion barrels of oil must be discovered or about 61 percent of the currently estimated undiscovered offshore oil. This amount

is about 8.6 times the amount discovered in the last 25 years.

Based on these projections for each year between 1985 and 2000, the following parameters pertinent to global offshore and gas are determined:

1. the average number of production platforms brought into operation per annum each producing 100,000 barrels per day — 35
2. the average amount of pipe to be laid and trenched per annum — 5,194 miles
3. the average size of the exploratory drilling rig fleet
   jackups 300; drillships 169; semisubmersibles 156 — 625
   (Daily operating costs $30,000, $40,000 and $60,000).

<u>Using these estimated parameters and the benefit quantitatives of the case studies, the unadjusted, global annual benefit to offshore oil and gas is estimated to be $658 million</u>.

This annual estimated benefit would be valid if all the offshore oil and gas activity envisaged took place in the southern North Sea. It is clear that this will not be the case but it is extremely difficult to forecast which regions of the world will be the significant offshore oil and gas producers in 1985-2000.

A judgmental distribution for offshore oil region production has been made for 1985 and with each producing region a weather factor has been assigned relative to the weather in the southern North Sea. With this judgmental allocation a weather weighting multiplier for 1985 of 0.579 is derived. This derivation for 1985 allocates a large weight to the northern North Sea because the actions of the governments of the United Kingdom and Norway appear to be fully in accord with a policy of achieving their desired productions in 1985. Beyond 1985, however, it seems today that governmental policy in the northern North Sea will seek to control the rate of the depletion of the existing oil and gas. Consequently, during 1985 to 2000 a weather weighting multiplier ranging from 0.359 to 0.579 is judgmentally thought to be appropriate.

<u>Using these factors and applying them to the unadjusted global annual benefit, the global annual regional weather adjusted benefit will lie between $236 million and $381 million</u>. This benefit range is the result of applying all forms and sources of weather and sea condition forecasting data to the operating problems of the offshore oil and gas industry.

In the case study relating to coastal zones, a judgmental evaluation of SEASAT's exclusive contribution to potential benefits was set at 30 percent* This is based on the data an

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*Econ, Inc. <u>SEASAT Economic Assessment, Volume V, Coastal Zones - Case Study and Generalization</u>, 1975.

operational SEASAT is expected to supply and its relevance to the models required for a wide variety of weather and sea condition predictions.

Consequently it is suggested that an annual benefit exclusive to SEASAT from offshore oil and gas activity during 1985-2000 will range from $71 million to $114 million. This is thought to be a most likely benefit range.

This benefit range, integrated over the years 1985-2000 but discounted to the beginning of 1975 is shown below as a function of discount rate.

Annual discount rate	0%	5%	10%	15%
SEASAT exclusive most likely benefit range ($ million, 1975)	1136-1824	476-765	214-344	104-168

Because the global offshore oil and gas industry is in a volatile stage of development and because it is very difficult to foresee what returns on investment may result from the various governmental developing policies with respect to exploration and production, the future price of oil and the success of specific applications of technology, a benefit uncertainty range has been developed. This uncertainty range attempts to span all sources of industry estimates for the size of the exploratory drilling rig fleet. Whereas the model projected a rig fleet of 700 by 1985, the uncertainty range would project from 300 to

1000 as the rig fleet size by 1985. The lower bound maintains the current rig fleet population. With these rig fleets, the lower bound leads to an annual benefit exclusive to SEASAT ranging from $29 million to $47 million and the upper bound to a range from $103 million to $166 million. Hence the annual benefit range exclusive to SEASAT from the oil and gas industry including uncertainty is estimated to be from $29 million to $166 million.

The discounted integrated benefit range with uncertainty exclusive to SEASAT as a function of discount rate, is shown below

Annual discount rate	0%	5%	10%	15%
SEASAT exclusive benefit range, with uncertainty ($ millions, 1975)	464-2656	195-1113	87-501	43-244

An independent study is presented, performed by the Canada Centre for Remote Sensing, which deals exclusively with future offshore and coastal oil production from the Canadian Arctic. Benefits are estimated from this regional study for the time period 1981-1990. If only benefits after 1985 are considered, then the time integrated undiscounted benefits of this independent study agree reasonably well with the benefits associated with this region as determined from the model for generalization, developed from the case studies.

3.2 Conslusions

The case study and its generalization reported in reference 1 estimated annual benefits, in 1974 dollars, ranging from <u>$85.6 million</u> to <u>$214 million</u>, to offshore oil and gas production platform erection and pipelaying. These benefits when adjusted by a factor of 1.1 to convert to 1975 dollars range from <u>$94 million</u> to <u>$235 million</u>, per annum from 1985 to 2000.

This current case study and its generalization estimates annual benefits from 1985-2000 of <u>$97 million</u> to <u>$553 million</u> for the activities of oil production platform erection, pipelaying and exploratory drilling. By assessing the industry's apparent intentions as reported in the trade literature during 1974-1975 the most likely benefit range is estimated to be from <u>$236 million</u> to <u>$381 million</u> annually.

Both benefit estimates are corrected for global weather and sea state regional influences relative to the southern North Sea and the current study employs an uncertainty factor associated with the size of the world's exploratory drilling rig fleet in 1985. The previous study only employed an extrapolation of global offshore oil production.

Both studies tend to agreement at the low end of the benefits, approximately $100 million per annum. Such a benefit results from the application of all data to the .

required simultaneous and concurrent prediction of global weather and sea conditions.

It is estimated that approximately 30 percent of this benefit or almost $33 million annually results exclusively from SEASAT's data application to the modeling required for prediction of weather and sea conditions, globally.

An annual benefit exclusive to SEASAT of $33 million per annum is concluded to be quite firm, from the offshore oil and gas industry during 1985-2000 provided that the data are disseminated and acted upon.

The derivation of benefits in both studies has been approached always with a conservative point of view. Yet the benefits must always evolve from the current forms of operations in the offshore oil and gas industry. The benefits can only be realized with perfect prediction of weather and sea conditions, if provision is made within these operations for alternative or contingent actions.

It is clear that today the oil companies and their contracted operators are coming to grips with the financial risks involved in offshore oil and gas exploration, particularly in those regions where the sea is inhospitable, including regions where operations must proceed through ice. With renewed financial evaluations, operational forms change continually as equipments and procedures move to a more efficient matching to the demands of the environment. Thus, technology and the search for operational economic viability

appear to move toward making the case study data obsolete to some degree.

For example, future production techniques tend to reduce the need for production platforms by using undersea, subsea or sea bottom well completions. This production form appears to be suitable for deep water production, is advantageous where oil-bearing geological formations or structures are difficult of access and promises an earlier cash flow return from production. Yet the technology and its adaptation to various production requirements is not yet established but its advent will reduce benefits established for production platforms. It is expected that, as the new technique is applied to production, avoidable economic losses will still occur which can be avoided by improved weather and sea-state prediction. It is reasonable, however, to expect that the requirements for prediction for subsea completions will be different from those for production platforms. In this study, the benefits to production platforms are estimated to be only about 1 percent of the total unadjusted benefit. Thus, a substantial change in this area would have only a small effect upon the benefits. It is difficult to forecast what contribution to benefits might arise from the technology of subsea completion. It is conjectured that this example will be typical of new technology introduced into oil and gas exploration and exploitation. Benefits will not disappear; they will be modified as will the prediction requirements of

weather and sea conditions.

Drilling and pipelaying are and will be fundamental to the offshore oil and gas industry. The character of pipelaying and the amount of pipe required may change appreciably with subsea completions, but again, predictions of these changes are not possible. Pipelaying could also be considerably influenced by various proposed forms of storage at sea with off-loading into tankers, but no trends to these activities seem to be established so that the influence can be assessed.

The benefits derived in these studies are reasonable and conservative. However, it is necessary to recognize that the case study data from which the benefits are developed may be only appropriate to earlier technology. Newer technology will, it is expected, still offer opportunities to realize benefits from improved sea condition and weather forecasting in the new forms that offshore oil and gas operations may take. To take advantage of the conditions which will permit the benefits to be realized, attention will have to be paid to the shifts in prediction of the pertinent sea condition and weather phenomena as new technology is introduced.

4. REVISIONS TO AN EARLIER CASE STUDY OF OIL PRODUCTION IN THE SOUTHERN NORTH SEA

A case study performed during 1974 investigated the economic losses resulting from unexpected weather conditions in the southern North Sea suffered by offshore oil production operations.*

The losses, derived from an actual operating log prior to 1971, were a result of accidents and nonproductive labor costs in erecting production platforms and laying and trenching production pipelines.

Benefits were assumed to result from accident avoidance and from reassignment of labor when adverse weather is predictable at least 48 hours in advance.

The case study benefit revisions for the North Sea are a consequence of increased operating costs and of an adjustment of the percentage of these costs that should be allocated to labor. These changes resulted from the current case study investigation of similar operations in the Gulf of Mexico and are thought to be more representative.

4.1 Pipelaying Operations in the Gulf of Mexico

Data for the case study of these operations came from a pipeline contractor's progress reports from an 18-month project. The progress reports are summarized in Appendices C and D.

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*Econ, Inc. <u>SEASAT Economic Assessment</u>, October 1974, p. 8-7 et seq.

A typical pipelaying operation involves equipment such as:

1 pipelaying barge
6 tugs
2 crewboats
1 supply boat
1 dredging barge

Representative daily charges (2 shifts) for this equipment are given in Table 4.1 during 1974. The total charge for this operation, including all forms of support, is estimated to be $100,000 per day. The crew of the pipelaying barge varied in size according to the work being performed. On a typical day of pipelaying, the following personnel were charged for each shift:

1 superintendent
1 barge captain
2 contractor representatives
5 inspectors
6 x-ray technicians
2 divers
2 diver tenders
2 tally men
20 welders
12 welder helpers
2 welder foremen
15 general laborers
1 medic (presumed 24-hour coverage)

Table 4.1 Representative Offshore Construction Charges During 1974 in the Gulf of Mexico

		Unit Hourly Rate	24 Hour Charge
1	Pipelaying barge 350' x 71 ' x 22.5' w/crew[1]	$ 1,800.00	$ 43,200.00
1	Dredge/work barge 250' x 60' x 16' w/crew[2]	925.00	22,200.00
6	1500 hp tug w/crew	70.00	10,080.00
2	84' crew boat	45.00	2,160.00
1	150' work/supply boat	58.00	1,392.00
1	150' x 40' offshore certified barge (supply)	10.00	240.00
	Superintendent	28.20	676.80
1	Welder, pipeline[3] (includes $1.75/hr offshore charge)	23.45	562.80
1	Welder helper (includes $1.75/hr offshore charge)	9.95	238.80
	Typical labor charge rate offshore is	$14.00 - $18.00	$336 - $432.

[1] Has quarters for 172 men

[2] Has quarters for 61 men

[3] Normal shift for hourly workers is 12 hours

Note: Estimated day rate for typical operation, based on catalog rates, is $100,000.

For a full 24 hours of operation, i.e., two 12-hour shifts, the pipelaying operation requires 120 men.

Three other typical operations were charged for, as shown in Table 4.2, requiring in some cases personnel in standby status. For this data it is concluded that a minimum of 37 personnel are required for the operation in addition to support personnel and crews charged with their equipment.

Consequently, it is deduced that approximately 80 personnel could be appropriately reassigned to productive tasks if sufficient notice was available of the arrival of weather sufficiently inclement to interrupt completely the pipelaying operation.

Reassignment would then apply that pipelaying operations would be impossible for 12 hours per day at least, so that prediction would have to include an anticipated duration of the inclemency.

Assuming an average personnel hourly rate of $16.00, the saving would then be 80 x 16 x 12 = $15,360.

Table 4.2 Personnel Charges in the Gulf of Mexico

Personnel	Hours Charges	Number of Personnel on Standby	Work Performed
120	12	0	Pipelaying; good weather
55	12	40	Installing riser; good weather
37	12	63	None; waiting on weather

If therefore, the sea condition prediction characteristics are appropriate, the minimum labor saving possibility is about 15 percent of the operation daily cost.

No explicit data are available to substantiate different personnel requirements in the North Sea. It is therefore concluded that a 15 percent allocation to labor is more reasonable than the 25 percent allocation used in the previous case study.*

For the pipelaying operation as a whole using 120 personnel, the daily labor charge is about $23,000 and the daily equipment charge is therefore about $77,000. This compares reasonably with $79,000 from Table 4.1 by direct addition for representative equipment charges.

The North Sea pipelaying equipment is considered to be more expensive to purchase than that for the Gulf of Mexico. The North Sea equipment daily charge is therefore increased by approximately 21 percent to $93,500. The daily labor rate in the North Sea is assumed to be equal to that in the Gulf of Mexico, approximately $23,000 per day. Thus, the total daily operating cost.

The revised findings of the previous case study are shown in Table 4.3 - the cost saving being reduced from $3,112,000 to $2,644,000, a reduction by about 15 percent.

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*ECON, Inc. SEASAT Economic Assessment, 74-2001-11, Contract No. NASW-2558, October 1974, p. 8-7 et. seq.

**Offshore, February 1975, p. 117. Quotes on daily rate for maintenancemen as $250 per day or about $21 per hour, a rate considerably higher than shown in Table 3.1.

Table 4.3 Summary of Revised Case Study Cost Savings

Maximum Operational Cost Savings Per Annum from Nonproductive Operating Costs	$ 2,644,040 (1974 $)
Number of Production Platforms	3
Miles of Pipeline Laid	38
Number of Operating Calendar Days Per Annum	272
Working Day Operating Costs Labor $23,000 per diem Equipment $93,500 per diem	$ 116,500
Weather Day Operating Costs (Equipment plus minimum crews)	$ 93,500

Operation Incident	Accident	Pipelaying Barge	Derrick Barge
Incident Occurrence No. Operating Days	11	64	22
Daily Cost ($)	105,000	15,360	23,000
Incident Cost Savings per annum ($)	1,155,000	983,040	506,000

Assumption: i) SEASAT operational capability available (1985)
ii) Operating incident data prior to 1971

The case study benefits of $2.644 million resulted from the emplacement of three production platforms and the laying and entrenchment of 38 miles of pipe to transport the oil produced.

Oil production from the North Sea is expected to grow between now and 1985, when SEASAT will become operational.

It was estimated during the previous case study that a representative annual incremental production would require an increment of seven platforms together with the laying of an incremental 250 miles of pipe.

For such an annual new production requirement the revised data from the Gulf of Mexico operations reduces this incremental annual benefit from $18.6 million to $15.9 million, a reduction of about 15 percent, as shown in Table 4.4.

Benefits A and B (Table 4.4) are considered to be benefits to the operations of pipelaying and trenching, whose total is about $14.6 million. Since this benefit arises from laying and trenching of 250 miles of pipe, the benefit per mile of pipe is $0.06 million. Benefit C is a benefit to the erection of seven platforms. Thus, the benefit per platform is estimated to $(1.36/7) million or $0.19 million.

Table 4.4 Revised North Sea 1979-1985 Oil Production Cost Savings

A. Accident Avoidance		
Projected Weather Related Accident Avoidance Ratio	4%	
Number of Pipelaying Barges (50 miles of pipe each)	5	
Length of Work	365	days
Daily Savings of Avoided Accidents (100% equipment costs +	$ 93,500	
50% labor costs) +	11,500	
	$ 105,000	
Potential Savings = 0.04 x 5 x 365 x 105,000	$ 7,980,000	
B. Pipelaying Labor Charge Savings		
Projected Weather Downtime Labor Charge Savings Ratio	23.5%	
Number of Pipelaying Barges	5	
Length of Work	365	days
Daily Savings on Labor Charges	$ 15,360	
Potential Savings = 0.235 x 5 x 365 x $15,360	$ 6,587,520	
C. Derrick Barge Labor Charge Savings		
Projected Weather Downtime Labor Charge Savings Ratio	42.3%	
Number of Barges Required per Platform Erection	2	
Number of Platforms Constructed/Yr.	7	
Number of Days Committed to Task	10	
Daily Savings on Labor Charges	$ 23,000	
Potential Savings = 0.423 x 2 x 7 x 10 x $23,000 =	$ 1,362,060	
Total Potential Savings = A + B + C =	$15,929,580	(1974$)

Note: Number of production platforms 7
Miles of pipe to be laid 250

5. EXPLORATORY DRILLING CASE STUDY - CELTIC SEA

Exploratory drilling or "wild catting" is performed by drilling rigs described as jackup rigs, drillships or semi-submersibles. Jackup rigs work most efficiently in shallow water; the drillships can work in deep water and are dynamically positioned; the semisubmersibles are operationally capable in very rough sea conditions such as those in the North Sea.

Because positioning for drilling tends to take days to establish, once established, the drilling rigs seek to stay on station, shutting down operations only when it is no longer possible to drill. In inclement weather resupply by supply boats may be impossible, while drilling could actually continue.

During drilling activity, accidents occur which are weather related and which, in the opinion of operating personnel, could be avoided. If appropriate forecasting was available and the information employed, ship downtime that results could be avoided.

The accidents identified in this case study came from the progress charts relating to the drilling of nine wells in the Celtic Sea by a single vessel during 1970-1974 through a total of 1,170 days.

5.1 The Case Study Data

By examination of progress charts, reported in Appendix A and from discussions (see Appendix B, E and F) with the sponsoring company's supervisor, accidents resulting in significant delays (Table 5.2) were identified. Table 5.1 does not include all accidents, only those resulting in a significant operating delay. One major delay was caused by a control panel fire and was unrelated to weather. Of approximately 1,170 total operating days over a five-year period, 87 days (or 7.4 percent) were lost to weather related accidents.

Experience over the years is summarized in Table 5.2. The average time spent waiting on weather was over 20 percent. When the weather delay time is tabulated by month, a pattern emerges, namely, a low average percentage during the summer (7 percent) and a high percentage during the winter (42 and 43 percent respectively for December and January). There is considerable variation throughout the year. The third highest delay (52 percent) occurred in May; the two previous Mays had no weather delays. The accidents are not distributed equally around the calendar but are concentrated in the relatively good months. Because of the relatively small sample, it may only be conjectured that this distribution is related to a combination of (1) expectations that the weather will be good and so risks are taken, and (2) when the ship is closed down for bad weather, fewer delaying

Table 5.1 Accident Caused Delays for Nine Wells in the Celtic Sea Drilled with a Drillship during 1970-1974 1,170 Total Days

16 Aug 70	35 days	With a storm forecast for midnight, the crew was preparing to close down. The storm arrived early and had associated with its 3 anomalous waves reportedly 60-feet high and quartering (45 degrees off bow or stern). The riser was dropped on the bottom.
27 Sep 70	12 days	With a weather warning, the riser was still bent before it could be retrieved.
11 Jun 71	10 days	The stack was dropped. A manufacturing defect was the proximate cause; it was associated with bad weather. A man was killed and a law suit filed.
15 Jul 71	10 days	Control Panel Fire. The fire was NOT associated with weather problems.
30 Mar 72	12 days	Anchor chain broken; resulting shift caused damage to equipment.
11 Apr 72	15 days	Two anchor chains broken; the damage to equipment in the well was so severe that it was abandoned.
15 Feb 72	3 days	Repairs to anchor chains.

Of approximately 1,170 total operating days over a five-year period, 87 days (or 7.4 percent) were lost to weather related accidents.

Table 5.2 Exploratory Drilling Vessel - Celtic Sea; Waiting on Weather Time - Monthly Percentages; Weather Related Accidents are Indicated by "Λ"

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1970					0%	4% 1 well 11,000'	0%	Λ 7.6%	Λ 30.9%	11.6%	35.8%	14.8%
1971	63%	36%	13%	39 days in dry dock	0%	Λ 12%	0% 1 well 11,900'	1%	4% 1 well 6500'	29%		No Record
1972	No Record	31% 1/2 month	Λ 31% 1 well 2800'	Λ 27%	52%	10% 1 well 7100'	1%	No Record		12%	28% 1 well 11,900'	70%
1973	22%	Λ 15%		No Record								
1974						2% 1 well 3500'	14%	12% 1 well 9500'	37%	27%	37% 1 well 6500 '	
Monthly Averages	43%	27%	22%	27%	17%	7%	7%	7%	23%	20%	34%	42%
Number of Months	2	3	2	1	3	4	4	3	3	4	3	2

Average of Monthly Averages 23%
Average over all Months 20%

accidents can happen. It should be noted that some of the accidents were caused by the onset of predicted bad weather before the ship was prepared.

Even if weather reports were significantly more reliable, not all accidents would be avoidable. One example from the sample was a possible manufacturing defect in equipment which was the proximate cause of an accident while the drillship was preparing for bad weather. From the sample, ten of the 87 days lost were thus unavoidable, even if a perfect forecast were available. On this basis, 6.5 percent of the days were lost to avoidable accidents; to be more conservative and because it is otherwise difficult to determine the percentage of avoidable accidents, the accident delay experience measured (7.4 percent) is reduced by one-half to 3.7 percent to account for unavoidable accidents. The adjustment also reflects the fact that, because the accident is weather related, some operational time would be lost even if the accident had not happened; frequently bad weather prevents repairs from being completed rapidly.

The case study findings are that a drillship operating during a period of 1,170 days (during a five-year period) suffered avoidable accidents which resulted in a 3.7 percent loss of time.

Assuming a daily drillship rate of \$30,000 per day and a 365 day operating year, the avoidable loss incurred is estimated to be \$407,000 per annum, for an operating drillship.

A drillship is assumed to be operationally effective throughout a year.

A semisubmersible is estimated to be susceptible to the same types of accident as the drillship and is also assumed to be operationally effective throughout a year. The daily rate for a semisubmersible is assumed to be $40,000. Hence, the same accident percentage for a semisubmersible implies an annual saving of about <u>$543,000</u>.

A jackup rig is assumed not to be susceptible to weather related accident lost time. However, jackup rigs are being built for deep water and severe weather conditions and it seems unreasonable to exclude them from accident susceptibility of the types tabulated in the case study which deals with risers, BOP stacks and positioning anchors.*

Accordingly, all drilling rigs will be assumed to be susceptible to a 3.7 percent loss of operating time arising from avoidable accidents that are weather prediction avoidable.

Day rates for drill rigs are undoubtedly quite variable. <u>Offshore</u>, February 1975, p. 48, gave the following figures:

Jackups	$30,000
Drillships	40,000
Semisubmersibles	60,000

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*<u>Offshore</u>, January 1975, p. 55.

Accordingly, accident related benefits to drilling rigs will be revised as follows:

Accident Annual Losses to Drilling Rigs

Drilling rig	Daily rate ($)	Annual Losses ($)
Jackup	30,000	407,000
Drillship	40,000	543,000
Semisubmersible	60,000	814,000

The values obtained are quite conservative when compared to a single accident loss of $5.4 million as discussed in Section 2.

5.2 Case Study Results Summary

Losses to the offshore oil and gas industry have been quantified for production, pipelaying and exploratory drilling.

These losses are all identified as being avoidable, provided that weather and sea conditions can be appropriately predicted ahead of time with sufficient quality.

The benefits are quantified as follows:

$0.06 million per mile of pipe laid and trenched

$0.19 million per production platform installed

$0.41 million per jackup rig drilling year

$0.54 million per drillship drilling year

$0.81 million per semisubmersible drilling year.

The benefits for pipelaying and production platforms require at least a 48-hour reliable weather and sea state forecast for the operating location.

The benefits for exploratory drilling require a 24-hour highly precise forecast to terminate or modify operations.

6. OFFSHORE OIL AND GAS INDUSTRY GENERALIZATION

The case study results, substantiated by practical operational data, are specific to the weather and sea condition environment of the southern North Sea and the Celtic Sea. These two sea environments are assumed to be identical in terms of the influence they may have on the operations of interest, production platform erection, the laying and trenching of pipe and exploratory drilling. The benefits derived will essentially become available to the industry only beyond 1985, or the time SEASAT becomes operational.

Generalization of these benefits requires a worldwide modeling of both oil and gas exploration and oil and gas production, in a reasonable manner consistent with current information, so that the incremental production and exploration beyond 1985 can be established.. The time horizon for benefit development will be the year 2000. Thus, to generalize for the offshore oil and gas industry, a projection of oil and gas production between 1985 and 2000 will be developed. It is clear that such a 25-year projection is very tentative because of the many pressures and constraints that exist. These pressures and constraints are political, legislative, financial and technological, and are almost impossible to evaluate. Hence the projection modeling procedure will in itself be extremely

simple, incorporating however many judgmental factors which appear today to be reasonable. The factors of interest will be presented in a subsequent section and then the model itself will be developed, followed by the generalized benefit estimation, together with some measure of the uncertainty of these benefits.

6.1 Offshore Oil and Gas Production Data Factors

The offshore oil and gas production process is a logical procedure which follows well defined steps each of which requires specialized equipment for its success. The procedure continues provided that the results of steps appear to be economically viable. This implies all forms of testing and evaluation of the results of each step.

The equipment employed is changing quite rapidly in its design concepts and capabilities. The costs of the activities are also changing quite rapidly. The search worldwide for offshore oil and gas necessitates adaptation of procedures to various forms of inclement sea conditions and weather and ice formations or, in the Arctic and Antarctic operations, on and through ice itself.

Certain statistics are very much needed to try to grasp the scale of the operations, in time and financially.
Benefits that this industry may enjoy are related to exploration and production offshore from 1985-2000. These activities are

very difficult to project largely because of costs, economics, licensing agreements, national legislation and ecological considerations. This section will try to give the flavor of the industry as it appears today.

6.1.1. The Oil and Gas Extraction Process

Various steps are generally followed in extracting offshore oil. Initially, following geological evaluation, there is a geophysical survey and sample core drilling to determine the mechanical properties of the seabed. Subsequently drilling for various purposes is performed from specialized rigs, known as jackups, semisubmersibles or drillships depending on how they are supported during the drilling operations. There are additionally other drilling structures called a platform tender, a self-contained platform and barge rigs which are used either separately or along with production platforms. Drilling activity is called exploratory or wildcat if oil discovery is the objective. When a discovery is made, appraisal hole drilling is made to determine the economic viability of the flows found in the discovery. Delineation drilling is then undertaken to produce wells to define the extent of the oil and gas that has been found and prior to production, development wells are drilled.

Development wells are joined by pipe to well heads which are connected to a production platform. The offshore production platform is a complete oil and gas production and

processing unit consisting of meters, separators, pressure vessels, compressors, pumps, generators and control equipment. Initially the production platform has drilling rigs associated with it. The platform provides also life support and safety equipment for up to 100 men and must maintain an inventory of supplies on board.

Oil produced can be pumped into floating storage in either a buoy or tanker, or more generally it is pumped through welded pipes, laid and trenched on the sea floor, which connect the production platform to an onshore storage. Pipelaying is performed by special barges or by pipelaying semisubmersibles.

In shallow water pipelines were joined or pipelines were connected to a riser by means of flanges welded above water. In deeper waters, welding is performed below water on the seabed in an inert pressurized atmosphere by saturation diving welders. Thus wells can be completed by a technique called subsea completion. The wells, essentially development wells, are drilled by semisubmersible rigs, which is asserted, to increase the demand for these rigs by 20 percent.*

Evidently each step in the procedure is dependent on the benevolence of the operating environment for its efficiency of accomplishment. Benefits from weather and sea condition forecasting are contained in economic losses which could be

*Offshore, January 1975, p. 57.

avoided if the environmental conditions were known ahead of time. This implies that there are optional procedures, preparation and actions that have been visualized and could be invoked which would allow avoidance of the losses being considered. The general improvement in statistical knowledge of the environment that satellites can provide will also serve specifically to allow trends to equipment design optimization. Otherwise there are many operating delays that sea conditions and weather introduce into operations which essentially cannot be avoided, only contended with, and which increase the cost of oil and gas production.

6.1.2 Offshore Oil and Gas Statistics

Geologists contend that the ultimate recoverable oil in the world is about 300 billion tons or 2,191 billion barrels. Already 40 billion tons has been produced, 90 billion tons is in proven reserves and 170 billion tons have yet to be discovered. Practically, geological estimates can be in error by a factor ranging from two to ten. The only definite means of identifying the quantity of oil is from drilling.

The 1973 world oil regional production is shown in Figure 6.1. The largest single oil reserve is in Saudi Arabia and is estimated to be 138 billion barrels.

The ultimate undiscovered recoverable offshore reserves has been estimated at 1,411 billion barrels or about 201 billion tons. During the last 25 years about 100 billion barrels of oil have been discovered offshore. The currently

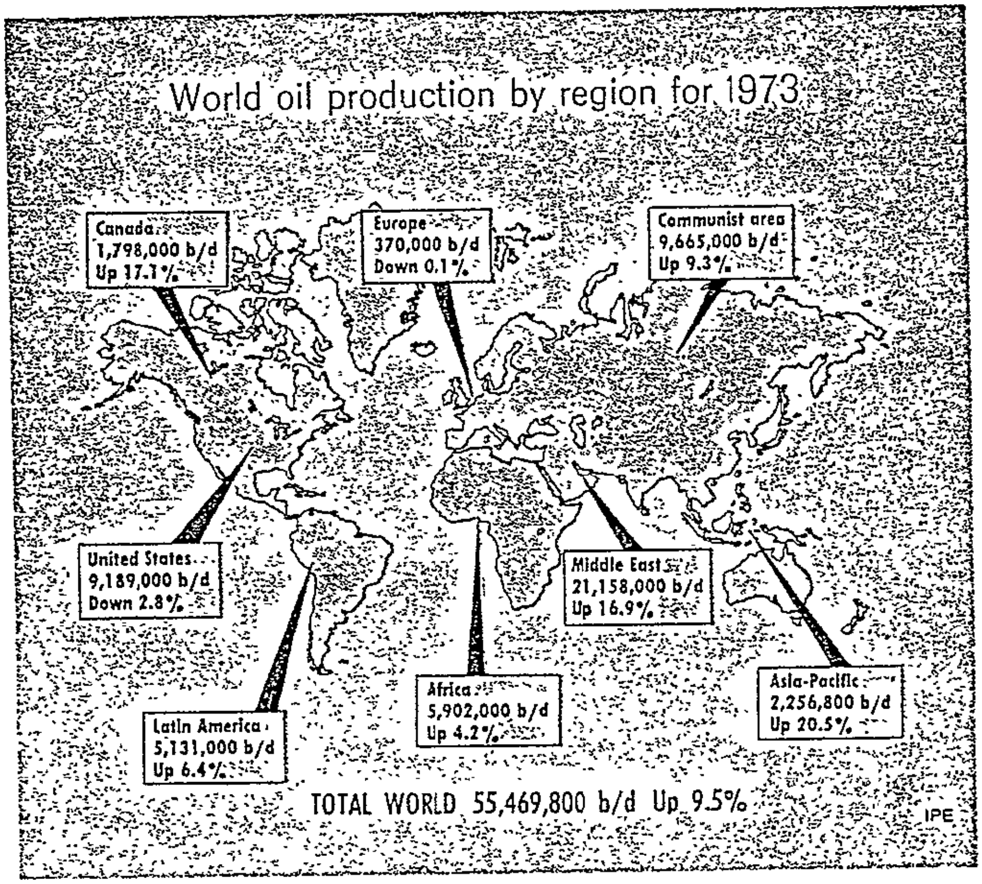

Figure 6.1 1973 World Oil Regional Production

proven offshore reserves are about 115 billion barrels, 73 billion of which lie within 40 nautical miles (nm) of the shore, the remainder being up to 200 nm from the shore.*

In 1972, offshore oil production was about 3.3 billion barrels or 9 million barrels per day, about 18 percent of the world's total

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*Offshore, January 1975, p. 57.

The world's gas reserve is estimated to be 2,033 trillion cubic feet, the largest single reserve being in the U.S.S.R. and is estimated to be 706 trillion cubic feet. The 1972 gas production was 500 trillion cubic feet, that of 1973 about 520 trillion cubic feet. The offshore gas reserve is estimated to be 181 trillion cubic feet and 1972 offshore production was about 50 trillion cubic feet or 10 percent of the world's total.

Between 1973 and 1974, world wide, about 18,804 miles of pipe was laid, and the incremental oil production was 5.6 million barrels per day and the incremental gas production was 20 trillion cubic feet. Using the conversion that 1 cubic foot of gas is equivalent to 1.7×10^{-4} barrels of oil and assuming that all pipe laid was for incremental production, the following incremental total is suggested:

incremental oil production	5.6 mb/d
equivalent incremental gas production	9.3 mb/d
incremental total	14.9 mb/d

This indicates that each incremental oil and gas production of 1 million barrels per day requires an associated 1,254 miles of pipe to be laid. In the North Sea, with an incremental production of about 4 million barrels per day it has been estimated that 6,835 miles of pipe will be required or about 1,709 miles of pipe per million barrel per day of production.

Oil and gas are depleted or produced on a worldwide basis which tends to keep the ration of reserves to production at about 30 to 1, but in some regions such as the U.S., this ratio is about 11 to 1, which is still considered to be healthy. To maintain a ratio evidently requires new oil discovery at the value of the desired ratio multiplied by the depletion rate.

A production well produces on the average about 2,500 barrels per day but it can range up to 10,000 barrels per day. Production pumps are either high volume 10,000 b/d or low volume 2,500 b/d.* Production platforms produce from 20,000 to 100,000 barrels per day, and although from five to 66 wells can be connected to one platform the most likely number being from 30 to 40, but an average is about 60 wells. These are development wells. To reenter a capped discovery well and complete it takes about two weeks. Each new offshore well takes from 30 to 40 days to complete so that a drilling vessel can complete about eight wells per year.**

To increase offshore oil production by one million barrels per day requires from ten to 50 production platforms and about 400 wells to be drilled which requires about 50 drilling vessel years to complete. This incremental production would require from 1,254 to 1,709 miles of pipe to be laid. To maintain the requisite reserves to production ratio

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*Offshore, May 1975, p. 165.

**Ibid., February 1975, p. 234.

then requires oil to be discovered at the rate of 4 to 11 billion barrels per year, depending on the ratio, as reserves.

In increasing offshore production incrementally during the next ten years by 5.1 million b/d will require 46 drilling rigs per year to be available.* This implies that 46 drilling rigs in a year are responsible for an incremental production of 0.51 million b/d or one drilling rig per year can introduce an incremental production of 4.05 million barrels or 11,000 b/d. Assuming each well produces 2,500 b/d, each drilling rig is completing only <u>four wells</u> per year, <u>not eight</u>. Evidently weather, sea state, the type of rig and the geological formations can cause such variation.

Exploratory or wildcat drilling offshore is more difficult to estimate because of the dry or nonproductive holes and because of delineation drilling and the size of a discovery per successful exploration hole. Frontier exploration in the Arctic gives one find for every ten wells taken down.** Worldwide, it appears reasonable to assume a success ratio of one in five. In 1973, 500 exploratory holes were drilled offshore.** The increment in reserves resulting from these exploratory holes is not known. It will be assumed

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*<u>Offshore</u>, January 1973, p. 56.

**Ibid., May 1975, p. 300.

***Ibid., February 1973, p. 53.

that during 1973 about 9 million barrels a day offshore were produced (this is the figure for 1972) and that the incremental production was 9 percent as for the world in general. Thus, the incremental offshore production in 1973 is estimated to be 81 x 10^4 barrels per day and if a 30:1 reserve to production ratio is assumed this implies a reserve increment of 24.3 million barrels per day or about 9 billion barrels. Thus, each of the 500 exploratory holes might be conjectured to lead to reserves of 18 million barrels or alternatively to an increment in production of 1,620 barrels per day.

Of the 500 exploratory holes that are drilled only 100 will actually produce a find. As time goes by it can be expected that exploration will become less and less successful, but what form the decrease in success will take is not known. Exploratory drilling can proceed at a rate of about five holes per rig per annum.*

Studies have indicated that 2,500 exploratory holes will have to be drilled in 1982**, and that in the North Sea between 1975 and 1985, 2,000 exploratory holes will be drilled in the North Sea.***

Studies have also identified offshore oil production in 1980 as 11 million b/d (free world)****; in 1985 as a minimum incremental production of 26.6 million b/d with other

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*Offshore, February 1975, p. 53.

**Ibid.

***Ibid., p. 73

****Ibid.

increments to 31.7 million b/d and 51 million b/d for the same year.* These estimates consider it reasonable to assume 30, 40 and 50 percent of the world's oil production to be offshore at that time.

The simple assumed growth in oil production is at the rate of 3.5 percent per annum. This gives a growth factor of 1.41 by 1985, i.e., a production of about 78 million barrels per day and a factor of 2.36 by 2000 or a production of about 130 million barrels per day. Such a growth rate is a reasonable one for financial purposes. Growth in offshore oil production is a very dependent parameter, dictated not only by price but by political objectives and national desires.

The worldwide offshore production and reserves as at the beginning of 1974 is tabulated in Table 6.1.**

6.1.3 Offshore Oil and Gas Economic and Cost Factors

Wells are qualified as economically viable for production based on the estimated recoverable oil and gas reserves, and the expected profit derivable from them in the world's market relative to all expenditures of exploration, development, production and transportation.

In the Arctic Islands a minimum recoverable reserve of

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*Offshore, January 1975, p. 55.

**International Petroleum Encyclopedia, 1975, pp. 267, 268, 269.

Table 6.1 Worldwide Offshore Production and Reserves

Country, state	Field	Discovery date	Well Depth ft	No. wells	1973 prod. (million bbl)	Cum. prod. 1-1-74 (million bbl)	Est. rem. reserves (million bbl)
ABU DHABI	Umm Shaif	1958	9,150	29	55	384	1,840
	Zakum	1964	9,100	43	106	471	812
CABINDA	Malongo N, S & W.	1966	1,300	110	51	182	500
ARGENTINA	Comodora Rivadavia	1907	NA	NA	0.7	NA	NA
AUSTRALIA	Barracouta	1968	4,500	5	2	8	494
	Barrow Island	1964	2,200- 6,700	318	15	83	125
	Halibut	1967	7,500	21	55	207	438
	Kingfish	1967	8,450	42	65	144	866
	Mubarras	1971	11,000	7	5	6	50
BRAZIL	Guaricema	1968	3,540	8	1	1	100
BRUNEI-MALAYSIA	Ampa S. W	1963	7,068- 8,155	84	45	223	2,118
	Baram	1967	9,500	24	14	38	63
	West Lutong	1965	6,800	19	19	63	86
	Bakau	1971		2	0 1	2	100
	Baronia	1970	11,000	1	0 4	0.9	75
	Champion	1970	4,300	8	8	12	92
	Fairley	1969	10,740	7	9	17	141
CONGO (Brazzaville)	Emeraude Marine	1969	1,930	14	12	13	500
	Pointe Indienne	1957	5,000	5	0.1	5	500
DENMARK	Dan	1971	5,900- 6,562	4	1	1	90
DUBAI	Fateh	1966	7,600- 8,500	27	49	179	1,404
	Fateh, S W.	1970	7,500- 9,000	12	32	32	1,000
EGYPT	Belayim	1954	7,000- 8,500	NA	NA	225	NA
	El Morgan	1965	5,500- 6,400	54	58.4	381	400
GABON	Anguille Marine	1962	8,300	16	10	43	131
	Port Gentil Ocean	1964	8,100	3	1	9	12
	Tchengue Ocean	1962	6,200	5	0.5	4	6
	Torpille Marine	1972	1,200	10	4	7	50
	Anguille, N E.	1968	7,480	10	4	17	146
	Anguille, N W.	1968	7,500	2	1	1	99

Table 6.1 Worldwide Offshore Production and Reserves (continued)

Country, state	Field	Discovery date	Well Depth ft	No. wells	1973 prod. (million bbl)	Cum. prod. 1-1-74 (million bbl)	Est. rem. reserves (million bbl)
GHANA	Block 10	1970	7,700- 8,500	1	SI	SI	NA
INDONESIA	Ardjuna	1971	3,760- 4,059	37	18	30	150
	Attaka	1972	600- 7,800	33	21	42	235
	Cinta	1971	3,450- 3,869	9	13	29	150
	Kitty	1973	3,000- 4,400	6	0.6	0.6	150
IRAN	Bahrgansar	1960	9,000-12,300	7	7	92	946
	Hendijan	1968	9,850-11,000	5	12	29	427
	Nowrouz	1966	8,587-10,850	10	15	39	930
	Cyrus	1962	7,000	8	8	38	776
	Darius	1961	11,000	11	40	290	1,044
	Rakhsh	1969	9,750	10	13	38	527
	Rostam	1966	7,200- 9,800	23	14	69	954
	Sassan	1967	7,500- 8,100	14	69	273	1,194
ITALY (Sicily)	Gela*	1956	10,800-11,150	10	4	70	82
	Ragusa	1954	12,460	30	3	103	40
JAPAN	Kubiki	1934	1,099- 6,370	133	0.4	9	15
LIBYA	Block 137	1972	NA	1	SI	SI	NA
MEXICO	Arenque	1970	11,362	6	3	6	994
	Atun	1966	9,040	10	2	27	896
	Cabo Nuevo	1967	5,753	3	0.6	8.6	10
	Isla de Lobos	1963	6,875	4	1	16	18
	Santa Ana	1959	9,517	10	0.4	28	10
	Tiburon	1965	7,314	6	0.4	4 7	20
NEUTRAL ZONE	Hout	1969	5,470- 9,130	26	21 7	70	929
	Khafji	1961	5,570-11,968	92	121	1,073	562
NEW ZEALAND	Kapuni	1959	11,323-12,504	4	1	2.5	9

Table 6.1 Worldwide Offshore Production and Reserves (continued)

Country, state	Field	Discovery date	Well Depth ft	No. wells	1973 prod. (million bbl)	Cum. prod. 1-1-74 (million bbl)	Est. rem. reserves (million bbl)
NIGERIA	Delta	1965	5,600- 9,400	11	7	37	89
	Delta, South	1965	7,100- 9,200	15	22	92	163
	Ekpe	1966	7,503	10	24	46	400
	Etim	1968	6,147	7	6	6	40
	Isan	1970	5,800- 9,000	10	9	13	41
	Malu	1969	4,800- 6,300	14	7	25	84
	Meji	1965	5,200-10,900	15	6	23	84
	Meren	1965	5,000- 7,500	34	33	146	382
	Okan	1964	5,500- 8,900	39	26	192	384
	Parabe	1968	4,500- 8,200	24	14	38	77
	Asabo	1966	5,412	7	12	47	176
	Idoho	1966	8,436	3	2	19	60
	Ubit ..	1968	4,842	15	11	35	79
	Unim	1966	5,914	7	14	21	65
	Pennington ...	1964	8,000-12,000	7	4.2	9.4	61
	Ulue . .	1966	5,014	5	7	8	43
NORWAY	Edda ..	1972	10,500	1	...	..	.
	Cod . . .	1969	9,750	1	...	..	.
	Ekofisk . .	1970	10,200-10,900	4	15	33	1,985
	Ekofisk West . .	1970	10,000	1	....		NA
	Eldfisk .	1970	9,500	1	..		
	Tor .	1970	10,000	1	(not producing)		NA
PERU	Humboldt	1960	3,000- 7,500	113	10	28	40
	Litoral and Mirad(	1960	6 000	93	2	25	18
	Procidencia	1967	3,000- 6,000	13	0.4	9.4	9 6
	Others	. .	. .	8	0 1	1.6	10
QATAR	Bul Hanine .	1970	6,000	10	17	20	100
	Idd El Shargi	1960	4,500- 8,250	14	15	138	1,977
	Maydan-Mahzan	1963	7,000- 7,600	11	56	359	9,890
SAUDI ARABIA	Abu Safah	1963	6,650	11	40	224	6,323
	Berri*	1964	7,450	37	227	450	5,476
	Manifa* .	1957	7,950	6	16	114	896
	Qatif* .	1945	7,050	4	42	417	8,623
	Safaniya* .	1951	5,100	82	351	2,658	22,178
	Zuluf	1965	5,800	7	29	29	100

Table 6.1 Worldwide Offshore Production and Reserves (continued)

Country, state	Field	Discovery date	Well Depth ft	No. wells	1973 prod. (million bbl)	Cum. prod. 1-1-74 (million bbl)	Est rem. reserves (million bbl)
TRINIDAD-TOBAGO	N. Marine	1959	3,000-15,000	1	.01	1	20
	Soldado	1955	5,100-11,000	219	18	243	168
	Brighton	1908	700- 7,500	189	1	64	68
	Galeota	1972	1,100- 6,300	15	0 6	0.7	10
	Teak	1972	7,250-15,191	12	15	16	60
UNITED KINGDOM	Forties	1970	7,000- 8,000	4	SI	SI	NA
UNITED STATES	Alaska, Granite Point	1965	8,772	25	5	52	38
	McArthur River	1965	9,572	52	39	214	176
	Middle Ground Shoal	1963	9,000	30	10	79	100
	Trading Bay	1965	5,650	42	8	49	26
	California, Algeria	1959	3,860	1	0.1	0 2	0.5
	Belmont Offshore	1948	3,644- 8,890	76	2	37	26
	Carpinteria	1966	3,892	122	4	41	31
	Coal Oil Point	1948	9,875	3	0.1	1	1
	Conception	1961	6,845	26	0.5	28.5	45
	Cuarta	1961	6,910	3	1	6	0 9
	Dos Cuadras	1969	3,673	129	17	87	88
	Elwood South	1966	6,289	20	0.9	6	15
	Huntington Beach*	1920	2,500- 5,000	463	21.6	884.1	129
	Rincon Offshore	1927	2,400-11,500	101	0.8	27	2
	Montalvo West*	1947	9,000-11,500	14	0.1	3	0 5
	Santa Ynez	1970	8,700-10,000	1	SI	SI	3,000
	Summerland Offshore	1958	NA	20	1	25	47
	Wilmington*	1926	2,200- 5,850	2,311	67	1,549	763
	Louisiana (giants only)						
	Bay Marchand Blk 2	1949	2,472-12,656	299	33	397	253
	Eugene Island Blk. 126	1950	4,000-12,000	54	5	85	40
	Eugene Island Blk 175	1956	11,500	82	10	29	81
	Eugene Island Blk 276	1964	6,083- 8,700	65	6	42	123
	Grand Isle Blk 16	1948	1,539-16,900	85	19	198	152
	Grand Isle Blk. 43	1956	2,325-13,600	222	21	143	227
	Grand Isle Blk 47	1955	4,096-13,614	89	5	61	39
	Bain Pass Blk. 35	1951	6,000	86	2	78	22
	Main Pass Blk. 41	1957	3,470- 8,047	121	15	134	146
	Main Pass Blk 69	1948	5,542- 8,791	169	11	183	77
	Main pass Blk 306	1969	6 167	125	7	26	124

Table 6.1 Worldwide Offshore Production and Reserves (continued)

Country, state	Field	Discovery date	Well Depth ft	No. wells	1973 prod. (million bbl)	Cum. prod. 1-1-74 (million bbl)	Est. rem. reserves (million bbl)
UNITED STATES *continued*	S. Marsh Island Blk 73	1963	5,790-11,695	44	5	36	69
	Ship Shoal Blk 204	1968	7,558-11,600	63	5	21	84
	Ship Shoal Blk. 207	1967	10,800-12,000	51	7	78	137
	Ship Shoal Blk. 203	1962	9,100-11,800	83	11	82	143
	South Pass Blk. 24	1950	6,500- 9,800	423	17	356	134
	South Pass Blk. 27	1954	6,542-15,592	241	13	247	138
	South Pass Blk. 62	1965	5,300-10,000	68	9	42	148
	South Pass Blk. 65	1969	8,033	79	12	36	154
	Texas, Federal Block 288	1956	6,600- 1,000	22	0.7	6	50
	High Island	1968	4,723-11,248	22	0.6	1	40
U. S. S. R.	Azerbaijan, Bakhar (Makarov Bank)	1968	12,800	7	5	12	NA
	Baku Archipelago (Sangachaly-Duvannyi-Bulla)	1963	8,773-16,608	100	36	136	900
	Izerbash*	1947	2,820- 5,800	50	1	21	NA
	Neftianye Kamni	1949	600- 5,406	1,200	45	760	500
	Turkmen, Cheleken	1961	3,116- 8,200	20	1	6	9
VENEZUELA Zulia State	Bachaquero**	1930	2,170	2,170	216	4,164	**
	Cabimas* **	1917	2,200	580	32	1,239	**
	Lagunillas**	1926	3,000	3,120	326	8,370	**
	Centro	1957	12,568	73	46	328	461
	Ceuta	1956	9,600-11,000	61	26	221	428
	Lama	1957	8,320	228	105	1,789	895
	Lamar	1958	13,003	73	53	646	1,195
	Mene Grande	1914	4,132	292	5	577	23
	Tia Juana*	1928	3,000	1,780	120	2,792	1,170
ZAIRE	GC-1X	1970	11,825	1	NA	NA	NA

NA—Not available. SI—Shut in (not producing). *—Partly onshore. **—Boliva. Coastal (30 billion bbl ultimate recovery)

500 million barrels is an approximate qualification for oil with a minimum of 19 trillion cubic feet for gas.*

In the North Sea, the reserves of the Cormorant field at 200 million barrels are described as meager although the field will go into production by pipeline linkage into another production complex.**

In 1973 development costs in the North Sea were estimated at $2,400 per barrel of oil per day produced; in 1974 this figure was revised to $3,700 per barrel of oil per day. In one field, Heather, these costs are estimated to be $7,000 per barrel per day, a field estimated to have a production capability of 50,000 barrels per day.

The Brent field in the North Sea with recoverable reserves of 2 billion barrels and an expected production from 300,000 to 500,000 b/d has been developed at a cost of more than $1.8 billion, about 8 percent of the total capital of its owners Shell and Exxon. Spending by British Petroleum (BP) in their Forties field development represents about 25 percent of BP issued capital and reserves.***

The development of the North Sea, United Kingdom sector by 1985, to a production level of 7 million barrels per day (official goal is about 2 to 2.8 million barrels per

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*Offshore, May 1975, pp. 300 and 301.

**Ibid., February 1975, p. 84.

***Offshore, January 1975, p. 106.

day) will require $25 billion of capital during the next decade and possibly an additional $10 billion for gas development.

During the next decade it has been estimated that offshore developments will require $770 billion of capital. The total assets of the world's 300 lending banks total $1.9 trillion. Four hundred fifty billion dollars is estimated to be required for placing platforms, development well drilling, buoy moorings or pipelines and shore terminals.* It is expected that offshore areas outside Europe and North America may suffer as a consequence of these large capital requirements.

Drilling exploratory holes can cost $3 million to $11 million per hole depending on location, as can all other types of drilling. Day rates for a drilling rig have generally been one-tenth of 1 percent of the rig's price, or $1,000 for each million dollars of a rig's cost. This is currently thought to be climbing to $1,200 to $1,500. A large semisubmersible equipped for deepwater drilling, costing $40 million, could have a daily rate of $60,000. Feasibility studies are being conducted for a larger new generation of semisubmersibles with a value of $80 million.**

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*Ibid.

**Offshore, May 1975,

Technology is providing compact semisubmersible drilling rigs (< 6,000 tons of steel compared to a giant > 9,000 tons of steel) expected to be priced at $22 million, cutting the day rate by 50 percent. It is thought that the compact vessels can operate very effectively in 300-600 feet of water. Some contractors believe that during the next decade most activity will really take place in these relatively shallow waters and the number of large semisubmersibles most effective in the hostile environment of the North Sea, Eastern Canada, Gulf of Alaska, Africa and Australia, may be curtailed. These hostile environments are in total about 5 percent of the offshore regions currently being developed.*.

The rig population for May 1975, including units under construction is shown as follows:

World Rig Population

	This Month May 1975			Six Months Ago Nov 1974			One Year Ago May 1974		
	Working	Idle	En Route	Working	Idle	En Route	Working	Idle	En Route
Louisiana	41	2	0	42	4	0	39	8	1
Texas	14	0	0	17	2	0	19	1	0
Mafla	5	0	0	..	..	..	..	..	..
U. S. Pacific	3	3	0	4	2	0	2	7	0
Africa	23	0	0	20	1	2	18	0	0
Atlantic	2	1	2	1	0	0	..	..	..
Australia	5	0	0	4	0	0	7	0	0
Canada & Great Lakes	5	5	0	13	1	0	7	3	0
Caribbean	3	0	1	3	0	0	2	0	0
Japan	1	0	0	2	0	0	1	0	0
Mediterranean	14	0	0	6	0	0	7	0	0
Mexico	3	0	0	3	0	0	3	0	0
Middle East	34	1	0	31	1	1	30	0	1
North Sea	48	1	1	45	0	0	41	0	2
South America	29	0	1	28	0	1	22	2	8
Southeast Asia	39	0	0	30	1	0	25	1	0
Total	275	13	5	249	12	4	226	22	7

Units under construction: drillship 51; jackups 63; semisubmersibles 59; total 163.

*Ibid., February 1975, p. 46.

The worldwide rig population, shown above was assumed for total existing rig units and under construction along with the average quoted contract drilling day rates.* Assuming an 85 percent utilization factor and assuming contract drilling to be about 50 percent of the total cost, drilling annual expenditures are about $4.5 billion, essentially for wildcats or exploration. Based on construction lead times of 24 months for shipshapes** and 30-36 months for semisubmersibles or jackups, and worldwide annual production of 50 units per annum and the need for 2,500 exploratory holes in 1982, there will be a requirement for 500 to 625 rigs at

Rig Type	Number	Assumed Average Day Rate	Daily Cost
Jackups	152	$ 15,000	$ 2,228,000
Drillships/Barges	69	20,000	1,380,000
Semisubmersibles	126	30,000	3,780,000
Total	347		$ 7,388,000

*Offshore, February 1975, pp. 48 et. seq.

**A shipshape is a ship used as a drilling platform drillship or conversion.

that time. A new design for a semisubmersible, fabricated in concrete at a price of $36 million, has a delivery of 15-18 months.

Based on the tabulated current rig population the projection to 1980 would give 564 rigs and 662 rigs by 1982. Allowing for retirements and losses, this should be in the range of drilling requirements,, and is about as far ahead as is reasonable for a projection of rigs because of economic, political and financial uncertainties.*

Current Mobile Exploratory Rigs (12/74)

	Existing	%	Under Construction	Total Projected (1978)	%
Jackups	134	51	55	189	45
Drillships/Barges	62	24	36	98	24
Semisubmersibles	64	25	63	127	31
	260	100	154	414	100

*Submersibles and tenders are excluded (Source: Offshore Rig Data Services)

Assumptions are that rigs can drill five or four holes per annum. In the Arctic rigs can most likely only drill three holes per annum.

Several rig forecasts have been published.* One forecast is parametric based on a 1985 world oil production of 102 million b/d of which offshore production could be 35, 40, 45 or 50 percent. The other rig demand is defined on the assumption of seeking to fully explore the estimated non-explored 201 billion tons of oil, offshore. The ideal rig fleet mix was determined from study of bathymetry in water depths to 3,000 feet, worldwide weather data, rig mobility and geological formations. It was concluded that there will be sufficient rough water work in demand in eastern Canada, Africa, Australia and the North Sea to keep the current, under construction and planned semisubmersible fleet fully occupied until retirement. Uncertainty, political and economic, when taken into account in the study leads to a conclusion that in 1985 40 percent or more of the worldwide production will be offshore with a rig demand for 600 units by 1982. Longer term estimates based on reserves and expected production lead to a conclusion of a demand for up to 60 new rigs per year for the next 15 years.

These projections (shown below) indicate that little attention has been given to economics, which are evidently sensitive to the price of oil and the price of capital.

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*Offshore, January 1975, p. 53, et. seq.

RIG FORECAST BASED ON OFFSHORE PRODUCTION

1985 offshore production, million b/d	35.7	40.8	46.0	51.0
1985 less 1972 offshore production, million b/d	26.6	31.7	36.9	41.9
Unplanned rigs required per year in 1976-1981	0	36	72	108
Retirements per year in 1975 at 1/2 of 20 year rate	5	5	5	5
Losses per year at 1% in 1975-1981	4	5	6	7
Total unplanned construction per year in 1976-1981	9	46	83	120
Cumulative unplanned construction in 1976-1981	54	264	498	720
Cumulative unplanned construction in 1982 operation	0	216	432	648
Cumulative planned and unplanned construction in 1982 operation	375	591	807	1,023

Note: Planned construction represents rigs that have already been committed for construction. Unplanned construction thus represents rigs not yet committed for construction.

IDEAL RIG MIX IN CONSTRUCTION

World oil production offshore			
Percentage of total production	40	45	50
Total units in 1982 operation	591	807	1023
Existing fleet plus unplanned construction			
Ideal 48% jackups	284	387	491
Ideal 27% drillships	159	218	276
Ideal 25% semisubmersibles	148	202	256
Unplanned construction only			
Jackups	123	226	330
Drillships	67	126	184
Semisubmersibles	26	80	134

RIG DEMAND 1975-2025 BASED ON RESERVES

Case	1	2	3	4
Construction period for unplanned mobile rigs (years)	25	20	15	10
Year last unplanned rig built	2000	1995	1990	1985
Estimated number rigs to perform subsea completion	72	72	72	72
Total number unplanned rigs at 25-year rig life	850	850	850	850
Number rigs/year to be constructed in 1976 and onwards	34	42	57	85
Number first class rigs in operation				
1975	375	375	375	375
1980	470	510	585	725
1985	565	645	795	1075
1990	660	780	1005	1000
1995	755	915	930	925
2000	850	840	855	850
2005	680	630	570	425
2010	510	420	285	0
2015	340	210	0	
2020	170	0		
2025	0			

Pipelaying rates are established in the following Brown and Root Inc. advertisement:

> *Brown & Root lay barge BAR-324 recently established a triple world record:*
>
> 1. *Laying 134 forty-foot lengths of 32" pipe in a 12-hour shift;*
> 2. *Laying 234 lengths in a 24-hour period*
> 3. *Sustaining a six-day average of 205 lengths of 32" diameter pipe per 24-hour shift.*
>
> *These records were established on a 110-mile, 32" diameter pipeline in depths of up to 420 feet. At the same time, BAR-323 was laying a 55-mile section of 30-inch pipeline in depths to 497 feet. The best rate on this project was 236 lenths in one 24-hour period. Until that time, no one had ever attempted to lay lines of such diameters at such depths*

Assuming that each pipe length is 40 feet, this establishes the pipelaying rate in 400-500 feet of water as something less than

$$\frac{236 \times 40}{5280} = 1.79 \text{ miles per day.}$$

Pipe is both laid and trenched, requiring special vessels for each phase of the work. Current costs are $20-$30 million for a trenching barge, $30-$40 million for a derrick barge and at least $50 million for a lay barge. In the later 1960's a derrick barge cost was $6-$8 million, and a 400 lay barge cost was $8-$10 million. A derrick barge in the deep North Sea that is used for platform construction and platform module installation may accomodate 200 men.

Assuming day rates for this equipment is as for rigs, i.e., $1,000-$1,500 per $ million of capital costs, the following rates are estimated.

Trenching barges	$20,000-$45,000 per day
Derrick barges	$30,000-$60,000 per day
Lay barges	$50,000-$75,000 per day

Pipelaying and trenching in 400-500 feet of water could then cost from $39,000-$67,000 per mile, assuming trenching proceeds at the same rate as pipelaying.

The largest pipelaying vessel in the world, which is 190 meters long is estimated to have a price of $56.4 million. Pipelaying studies indicated that pipe of up to 50 cm diameter (20 inches). can be layed in water of depth from 300-400 meters (980-1,310 feet).

Northern North Sea production platforms are physically about twice as large as anything produced before. Platforms are standing in 500 feet of water, the latest discovery in the northern North Sea, the Magnus field, is in 623 feet of water. Studies have indicated production feasibility in up to 800 feet of water.

The platform structures are either fabricated from steel or from concrete. The operational components of the platform are added in modules that weigh each about 1,200 tons and need special derrick barges to lift them.

Platform structures are priced from $60 million to $84 million. The installed platform costs are $85 million to more than $144 million. In December 1974 a platform was ordered for the Ninian field at a price of $140 million, with delivery set for summer 1977, about 30 months later. Final delineation of this field was completed in September 1974 and production is expected in 1978. The Forties field was discovered in 1970. Initial production is expected in July 1974 at which time the pipeline will be completed. In the Norwegian sector the Stratfjord

field was discovered in March 1974 with recoverable reserves of 2 billion barrels and 1.8 trillion cubic feet of gas. It is expected to go on stream in 1980 at which time the Norwegian production is planned to be 374 million barrels of oil and 1.06 trillion cubic feet of gas. Production from the Ekofisk field in 1974 was 13.4 million barrels, for 1975 the plan is for 54.3 million barrels and for 1976 the plan is for 189 million barrels. In other fields, production will move from 100,000 barrels/day in 1974 to 500,000 barrels/day in 1976. It is worth noting that a compressor problem in production has delayed an increase in production from 40,000 barrels/day to 100,000 barrels/day from mid-1974 to late 1975.* This gives some relativity to benefit from weather in relationship to benefits from equipment design and reliability. At $5.00 per barrel the oil not produced has a basic value of about $110 million for which the capital cost alone could be $11 million.

Drilling capability is in water depths up to 3,000 feet. The jackup from 20 to 300 feet; drillships from 40 to 3000 feet; semisubmersibles from 100 to 3,000 feet. Conventional moorings using anchors are limited to 1,000 to 2,000 feet. Drilling guidelines are being replaced by acoustical reentry. Blow off preventers (BOP) are designed to operate in more than 2,000 feet of water, with a capability to go to 4,000 feet and are ready to go to 6,000 feet. The riser for mud

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*Offshore, February 1975, p. 71.

recirculation is currently the impediment to drilling up to 5,000 to 10,000 feet.

Dynamic positioning is considered to be adequate to drilling in from 500-10,000 feet of water and position has been held in a combination of 22-foot-high waves, 65-mph winds and 1.5-knot currents. Many components are in short supply such as electric motors, bearings and transformers. Drill casings and drill pipe have a four-year ordering lead time.

Supply support is of great concern in heavy weather operations. An incident is cited of a 21-day delay in delivery to a rig of essential drilling supplies because of heavy weather which, at $75,000 per day cost about $1.6 million.* Again, this gives relativity to losses from weather prediction inadequacies.

Offshore oil hot spots or regions for exploration are identified as the North Sea, eastern Canada, the East Coast of the United States and the Gulf of Alaska. Future areas are the Bering Sea and Bristol Bay, the offshore Beaufort Sea, the offshore of Prudhoe Bay and the Arctic Island area.** Other regions of great promise are the Mediterranean, the Phillippines, Indonesia, the Indian Ocean and the Formosa Straits.

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*Offshore, February 1975, p. 117.

**Ibid., p. 110, et. seq.

The Indian Ocean potential reserves and rig activity are tabulated as follows:

INDIAN OCEAN RIG ACTIVITY 1970-1975						
	1970	1971	1972	1973	1974	1975
South Africa	2	2	1	1	1	
Mozambique	3	2	1			1
Malagasy Republic	2	3			1	
Oman		1	1			
India				1	1	2*
Sri Lanka (Ceylon)						
Tanzania				1	1	
Pakistan			1	1		1
Somalia					1	
Open Sea			1	1		1
Total	7	8	5	5	5	5

*One will move into this area this year.

POTENTIAL INDIAN OCEAN OIL RESERVES	
Country	Billion bbl
Malagasy Republic	1 - 10
Mozambique	1 - 10
Tanzania	1 - 10
Kenya	1 - 10
Somalia	1 - 10
P.D.R. Yemen	1 - 10
Oman	10 - 100
Pakistan	10 - 100
India	10 - 100
Sri Lanka	0.1 - 1
Bangladesh	1 - 10

POTENTIAL INDIAN OCEAN GAS RESERVES	
Country	Trillion cu ft
Malagasy Republic	1 - 10
Mozambique	10 - 100
Tanzania	1 - 10
Kenya	0.1 - 1
Somalia	0.1 - 1
P.D.R. Yemen	1 - 10
Oman	1 - 10
Pakistan	1 - 10
India	10 - 100
Sri Lanka	0.1 - 1
Bangladesh	10 - 1000

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*Ibid., April 1975, p.

6.2 Worldwide Oil and Gas Production Projections

Data and factors from the last section will be selected and composed into a single model which will project offshore oil and gas production and exploration from 1975 to the year 2000.

6.2.1 Modeling Considerations

Current deep water production platforms cost about $140 million installed. It will be assumed that an onshore facility to receive, process and distribute the received oil will cost about the same.

Pipeline capital investment is about $8 billion for 6,835 miles of pipe or about $1.2 million per mile. Since pipelaying and trenching on the average costs about $53,000 per mile, this cost will be assumed to be included in the $1.2 million figure.

If a production platform produces about 100,000 barrels of oil per day, then associated with the platform is from 125 to 175 miles of pipe at an investment cost of about $150 million.

Thus, in a very simplified manner each production complex can be estimated to require an investment of about $450 million. In the next decade the capital requirement for production has been estimated at $450 billion.* This implies 1,000 production platforms, whose total production would be

*Offshore, May 1975, p. 442.

about 100 million barrels per day of oil or gas equivalent. This is an estimated incremental production after some as yet undefined time interval, even though the capital is an estimated requirement before 1985.

Production in the Gulf of Mexico, which exceeded all the experts estimates proceeded as follows.

Year	Production
1947	3400 barrels
1957	52.8 million barrels
1967	284 million barrels
1970	401 million barrels
1974	311 million barrels

Excluding the first decade production increases are by a factor, five in ten years and a factor seven in 20 years approximately. Given the current oil extraction urgency and also the demand for investment capital it does not seem unreasonable that 100 million barrels per day may be achieved in 25 years (2000) from the current production of about ten million barrels per day.

<u>It will therefore be assumed that 100 million barrels per day by 2000 will be a reasonable production goal for offshore oil alone</u>.

If this is reasonable then the production in 1985 must be determined to generalize the benefits of SEASAT to both exploration and the production of oil and gas.

To achieve such an increment in production requires appropriate drilling activity to discover and to establish reserves. If the current offshore production is ten million barrels per day or about 3.7 billion barrels annually then the current reserves of 115 billion barrels support this production at a ratio of 30:1, reserves to production. The major constraint, as far as reserve development is concerned, is the estimated 1,411 billion barrels of undiscovered offshore oil. If the average production per day over 25 years is 55 million barrels, then the integrated consumption over the time period would be 502 billion barrels which seems reasonable in terms of the undiscovered oil that is estimated to exist.

To try and develop a systematic estimate of production with time, the following assumptions will be made.

1. At January 1st, 1975 there were 300 prime operating rigs.
2. Shipyards can produce 50 rigs per year. Rigs become obsolescent at the rate of five per year and about five rigs per year are lost to a variety of causes at sea. Thus, the incremental annual increase in rig population is 40.

3. Rig production will be pursued until 1985 at which time no new rigs will be produced. By then it is reasoned the world's shipyards will be concentrating on production platform production and the construction of sea going equipment necessary to production.
4. Exploration drilling will be performed at the rate of four holes per annum per vessel.
5. Each such hole drilled will add 1,620 barrels per day to eventual production or 18 million barrels per oil to reserves.
6. During the period up to 1985 it will be assumed that from discovery to production takes five years; from 1985 to 2000 it will only take four years. This is an improvement developed from learning, etc.
7. Exploration beyond 1985 will not be as successful as prior to 1985. Tentatively the success will be linear, declining from 1 in 1985 to 0.5 in 1995 remaining constant beyond.
8. The drill rig fleet will be fully utilized.
9. Each one million barrels per day of production requires from 1,254 to 1,709 miles of pipe to be laid and trenched.

With these assumptions the following simple method exploration and production is developed, Table 6.2.

Table 6.2 Offshore Oil Exploration and Production Model

Date	Prime Drilling Rigs Operating	Exploratory Holes Per Annum	Associated Incremental Production Millions b/d	Exploration Relative Success Factor	Increment To Production Millions b/d	
1/1/75	300	1200	1.94	1	1.94	
76	340	1360	2.20	1	2.20	
77	380	1520	2.46	1	2.46	
78	420	1680	2.72	1	2.72	
79	460	1840	2.98	1	2.98	
80	500	2000	3.24	1	3.24	
					15.54	Incremental production prior to 1985
1/1/81	540	2160	3.50	1	3.50	
82	580	2320	3.76	1	3.76	
83	620	2480	4.02	1	4.02	
84	660	2640	4.28	1	4.28	
85	700	2800	4.54	1	4.54	
					20.10	Incremental production between 1985 and 2000
1/1/86	690	2760	4.47	0.95	4.25	
87	680	2720	4.41	0.90	3.97	
88	670	2680	4.34	0.85	3.69	
89	660	2640	4.28	0.80	3.42	
90	650	2600	4.21	0.75	3.16	
91	640	2560	4.15	0.70	2.91	
92	630	2520	4.08	0.65	2.65	
93	620	2480	4.02	0.60	2.41	
94	610	2440	3.95	0.55	2.17	
95	600	2400	3.89	0.50	1.95	
96	590	2360	3.82	0.50	1.91	
					32.49	Incremental production between 1985 and 2000
1/1/97	580	2320	will not give rise to any production until after the year 2000			
98	570	2280				
99	560	2240				
2000	550	2200				

6.2.2 Results of the Model

Assuming the 1974 offshore oil production to be ten million barrels per day, the incremental production prior to 1985 will be 15.5 million barrels per day, for a total production in 1985 of 25.5 million barrels per day. Incremental annual growth is shown in the model.

Between 1985 and 2000 the incremental production will be (20.1 + 32.5) or 52.6 million barrels per day for a total production in the year 2000 of 78.1 million barrels per day. This total production is less than the 100 million barrels per day that seemed reasonable. The discovered reserves will then have to be about 855 billion barrels of oil or about 61 percent of the estimated currently undiscovered offshore oil. This amount is about 8.6 times the amount discovered in the last 25 years.

During the years from 1985 to 2000, 526 production platforms will have to be fabricated and installed, each capable of producing 100,000 barrels of oil per day. Production will also require from 65,940 to 89,893 miles of pipe to be laid and trenched. The drilling rig fleet will be assumed to have the ideal composition of 48 percent jackups; 27 percent drillships and 25 percent semisubmersibles, these ratios holding throughout the time period of interest.* The composition at its maximum in 1985 would then be:

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*<u>Offshore</u>, January 1975, p. 53.

Jackups	336
Drillships	189
Semisubmersibles	175

A conservative estimate of the world's total oil production, using a growth factor of 3-1/2 percent per annum, is that in 1985 it will be 78 million barrels per day and in the year 2000, 130 million barrels per day. Thus, in 1985 and 2000, offshore oil accounts for about 33 and 60 percent of the world's total oil production.

The estimated investment capital required for the model's output between 1975 and 2000 is identified as follows.

Production capital $(681 x 450) million	$ 306 billion
Development capital $3500 x 68.1 x 10^6	238 billion
Drilling rig capital	
192 jackups at $30 million	6 billion
108 drillships at $40 million	4 billion
100 semisubmersibles at $60 million	6 billion
Estimated total capital requirement	$ 560 billion

The average annual capital requirement is about $22 billion. The annual cost for drilling will be between about $5 billion and $11 billion depending on the number of prime rigs operating.

The financing requirements are appreciable. Up to 1985 however the capital needs are about $140 billion or about 11 percent of the estimated capital needs of the oil industry by this time for about 33 percent of the production.*

6.3 Generalized Offshore Oil and Gas Benefits (1985-2000)

From the model the following benefit variables are extracted for 1985-2000.

Production platforms emplaced	526 (100,000 b/d)
Average amount of pipe laid	77,916 miles
Average annual size of drilling rig fleet	625
Average number of platforms per annum	35
Average amount of pipe laid and trenched per annum	5,194 miles
Drilling rig fleet	
Number of jackups	300
Jackup daily cost	$30,000
Number of drillships	169
Drillship daily cost	$40,000
Number of semisubmersibles	156
Semisubmersible daily cost	$60,000

*Offshore, May 1975, p. 442.

Using these variables, without adjustment for either the regional weather relative distribution over the world's offshore oil production regions or for benefits exclusive to SEASAT's data contribution the benefits in Table 6.3 are estimated, using the case study derived benefit figures.

Thus, the estimated worldwide unadjusted annual benefit to the offshore industry as a result of loss reductions in production and pipelaying and exploratory drilling is \$657.8 million. If all the envisaged activity took place in an environment with weather and sea conditions identical to the southern North Sea then this would be the annual potential benefit.

To the extent that worldwide offshore oil production is located away from the southern North Sea this potential benefit must be adjusted. How this production will be actually

Table 6.3 Unadjusted Annual Generalized Offshore Oil and Gas Benefit

To platform construction	35 x \$0.19 million	=	\$ 6.7 million
To pipelaying etc.	5194 x \$0.06 million	=	311.6 million
To jackups	13.51 x 300 x \$30,000	=	121.6 million
To drillships	13.51 x 169 x \$40,000	=	91.3 million
To semisubmersibles	13.51 x 156 x \$60,000	=	126.6 million
Total unadjusted annual benefit			\$ 657.7 million

generated between 1985 and 2000 is difficult to forecast because of the expectation of political and economic control of depletion rates, licensing practices by various national jurisdictions and the movement to national oil self-sufficiency by many nations, as well as the economic and ecological constraints on development, and the future price of oil.

By 1985 it seems clear that the governments of Great Britain and Norway will have moved their oil resources into healthy production compared to 1975. It seems also likely by then that production from the Gulf of Mexico, Persian Gulf, Venezuela and the South China Seas, possibly also West Africa and Australia,will not have shifted greatly in a relative sense. California by then could be a strong producer as could the Indian Ocean, Indonesia and the Mediterranean. It is not however clear what assumptions might be reasonable about the Arctic, eastern Canada and the eastern United States.

Yet by 1985, following the results of the model the incremental oil production must have increased from ten million barrels per day to 25.5 million barrels per day.

By 1985 a large fraction of the incremental production could be accounted for as follows:

United Kingdom southern North Sea	1	million b/d
United Kingdom northern North Sea	6	million b/d

Norway northern North Sea	2.2 million b/d
General producing regions increment from 1975	4 million b/d

This gives a form to about 85 percent of the estimated increment. The remainder, some 2.3 million b/d could be distributed throughout the world, 75 percent in weather and sea condition benign region, 25 percent in weather and sea condition regions comparable to the southern North Sea. In concept the benign regions are the Indian Ocean, Indonesia and the Mediterranean, the nonbenign regions in the Arctic, eastern Canada and the eastern United States. The subdivision is a judgmental one, reflecting the technical difficulties in oil production.

This is the period of a great rush to get the North Sea into production. It appears that beyond 1985 the incremental production will be well controlled, by the governments involved.

By 1985 California may be producing one million b/d, provided that the ecological problems can be resolved.

Table 6.4, Offshore Oil Weather Weighting, indicates the weighting applied to the previous offshore oil generalization.* This particular table will be reconstructed judgmentally to reflect what might be reasonable in 1985 as Table 6.5.

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*Econ, Inc., SEASAT Economic Assessment, 74-2001-11, contract NASW-2558, p. 8-7 et. seq.

Table 6.4 Offshore Oil Weather Weighting

World Offshore Production Percentage	Major Offshore Producing Area	Beaufort Frequency % (1) (2)	Beaufort Frequency/ Frequency for North Sea	Weighted Relative Frequency %
2.5	North Sea	10	1.0	2.5
7	Gulf of Mexico	2	.2	1.4
25.5	Venezuela	0.5	.05	1.275
3.9	Bass Straits	14	1.4	5.46
4.1	South China Seas	0.3	.03	0.123
1.8	Gulf of Alaska	9	.9	1.62
36.6	Persian Gulf	0	0	0
6.5	West Africa	1	.10	.65
3.2	California	0.5	.05	.16

World Multiplying Factor Relative to the North Sea = $\frac{10.688}{2.5} \cong 4$

Reference: (1) U.S. Navy, Marine Climatic Atlas of the World, Navair 50-1C-54, 1 March 1969.

(2) U.S. Department of Agriculture, Weather Bureau Atlas of Climatic Charts of the Oceans, 1938.

Table 6.5 Offshore Oil Weather Weighting

Region	Production %	Relative Weather Factor	Weather Production Weight
Southern North Sea	3.9	1.0	0.039
Northern North Sea	32.0	1.4	0.448
Gulf of Mexico	5.5	0.2	0.011
Venezuela	14.0	0.05	0.007
Bass Straits	2.1	1.4	0.029
South China Sea	2.3	0.03	0.001
Gulf of Alaska	1.0	0.9	0.009
Persian Gulf	20.0	0	0
West Africa	3.5	0.1	0.004
California	3.9	0.05	0.002
World (rough)	2.9	1.0	0.029
World (smooth)	8.9	0	0
			Σ = 0.579

As a percentage of production, based on a 1985 production of 25.5 million barrels per day, one million barrels per day is about 3.9 percent. Changes to Table 6.4 are introduced to reflect the expectations from the southern and northern North Sea and California. Other world producing regions are assumed to produce incrementally by a factor of 1.4, a growth at 3-1/2 percent per annum for ten years. To complete the percentage distribution, the nonregionally accounted percentage, 11.8 percent, is split 25 percent into world rough and 75 percent into world smooth with factors for the weather of 1 and 0. Weather weightings also reflect reasonably well the occurrence of storms which are significant to exploratory drillings. The derived value of 0.579 is conservative within the technique employed because it is based on total production and not incremental production. To define an alternative weighting factor, up to 2,000, assuming the northern North Sea production remains essentially constant beyond 1985, the weight for the northern North Sea, 0.448, will be multiplied by the average regional relative weather factor of 0.51 to give a weight for its uniform distribution of 0.228. A benefit weight due to weather that would be reasonable from 1985 to 2000 would then lie between 0.579 and 0.359.

6.4 Weather Adjusted Annual Benefit

The total unadjusted annual benefit was estimated to be $658 million.

It is estimated that a reasonable weather adjustment factor for the world's offshore oil production between 1985 and 2000 would be between 0.359 and 0.579. Hence, the adjustment annual benefit to the offshore oil and gas industry will range from $236 million to $381 million.

6.5 Weather Adjusted Annual Benefit Exclusive to SEASAT

In the study of Coastal Zones, a judgmental estimate was made of the influence of an operational SEASAT's data on models that would be used for prediction, in particular of coastal zone storminess.* The matrix of influence is reproduced in Table 6.6. From this matrix and from experience with modeling*, judgmentally estimated benefits to SEASAT to be 30 percent of the essentially potential benefits within an operation.

Such a judgmental factor seems reasonable for this application also. Hence, it is suggested that the annual benefit from offshore oil and gas which are exclusive to SEASAT will range from $71 million to $114 million.

6.6 The Uncertainty in the Calculated Benefits

In an industry such as the offshore oil and gas industry which is in 1975 at a very volatile state of development, considerable uncertainty exists in trying to project what will happen 25 year hence.

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*Econ, Inc., SEASAT Economic Assessment. Vol.V, Coastal Zones-Case Study and Generalization, 1975.

Table 6.6 Model Influence for SEASAT Measurements

Model	SEASAT Measurement					
	Surface Winds	Surface Waves	Atmosphere Profiles	Topography	Surface Temperature	Sea Ice
Marine Wind Analysis Model	4	0	0	0	2	1
PE Atmospheric Forecast Model	3	2	4	0	3	1
Ocean Circulation Model	4	2	0	4	3	1
Hydrodynamic Numerical Models	4	0	0	3	0	1
Surface Current Models	4	3	0	4	3	1
Thermal Structure Models	1	3	0	2	4	1
Heat Exchange Models	4	0	3	0	4	0
Spectral Wave Models	4	4	3	0	1	1
Ocean Tidal Models	0	0	0	3	0	0
Dispersion/Diffusion Models	4	4	0	0	3	0
Search and Rescue Models	4	4	0	0	3	2
Ocean Front Models	3	1	0	3	4	0
Acoustic Propagation Models	0	4	0	0	4	2
Storm Surge Models	4	3	0	3	0	0
Surf Models	0	4	0			1

Code:
- 4 Critical Direct Influence
- 3 Major Direct Influence
- 2 Minor Direct Influence
- 1 Slight Direct Influence
- 0 No Influence

Some quantitative measure of uncertainty can be made by considering the range of drilling rigs and their growth characteristics that have been suggested in the literature. At the low end it can be considered that new construction will just maintain the rig fleet at 300 until 1985 at which time it will naturally decay at the rate of ten rigs per annum. At the high end new construction will be emphasized to create a rig fleet of 1,000 in 1985 after which the fleet size will decay at the rate of ten per annum.

This uncertainty produces changes both in anticipated production and the average annual size of the rig fleet. These changes, then can be used to determine the magnitude of uncertainty in the benefits as shown in Table 6.7.

The weather adjusted annual benefit, with uncertainty, can range from $97 million to $553 million, with a most likely annual benefit ranging from $236 million to $381 million.

<u>The estimated annual benefit to SEASAT, with uncertainty can range from $29 million to $166 million with a most likely annual benefit ranging from $71 million to $114 million</u>.

The benefit uncertainty, as related to the size of the world's drilling rig fleet, is in some manner a measure of the relationship among the price of oil, the various worldwide leasing agreements and the general ability to keep exploitation costs within reasonable bounds as a consequence of improved technology and its relatively precise application to the operations to be performed. This relationship at this time is either too complex or too tenuous to unravel.

Table 6.7 Benefit Uncertainty Calculations (1985-2000)

1985 rig fleet	300	700	1000
1975 production mb/d	10	10	10
1985 production mb/d*	21.6 (27.7)	25.5 (32.7)	28.5 (36.5)
2000 production mb/d*	45.9 (35.3)	78.1 (60.1)	103.3 (79.5)
Production increment by 1985 mb/d	11.6	15.5	18.5
Production increment 1985-2000 mb/d	24.3	52.6	74.8
% incremental production 1985-2000 mb/d	46.2	100	142.2
Average annual number of rigs 1985-2000	225	625	925
% number of rigs 1985-2000	36.0	100	148
Unadjusted annual benefit to production ($ million)	147.1	318.3	452.6
Unadjusted annual benefit to rigs ($ million)	122.2	339.4	502.3
Total unadjusted annual benefit ($ million)	269.3	657.7	954.9
Weather adjusted annual benefit range ($ million)	97-156	236-381	343-553
SEASAT exclusive annual benefit range ($ million)	29-47	71-114	103-166

*Parentheses identify the percentages of expected world oil production. In 1985 this is estimated to be 78 mb/d; in 2000, 130 mb/d.

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6.7 Integrated Benefits

The annual benefit ranges, with uncertainty, have been identified. To determine the integrated benefit over time, each annual benefit for each given year is discounted from the given year back to 1975 at some appropriate interest rate. In this study benefits are assumed to be accumulated only at the end of the year 1985 and henceforward to the end of the year 2000. Annual benefits are then discounted to the beginning of 1975. The first annual benefit discounting time period is therefore 11 years and the last is 26 years. Annual benefits, equal each year, are then simply multiplied by an integrated discount factor which depends on the interest rate used.

The multiplying factors to the annual benefit, as a function of interest rate, are shown below.

Interest rate	0%	5%	10%	15%
Factor	16	6.7073	3.0162	1.4716

The integrated benefit as a function of discount rate is tabulated in Table 6.7.

6.8 An Independent Study of Oil in the Canadian Arctic

In the Arctic regions all activities and operations necessary to oil production and transportation are strongly influenced by the presence of ice, either as icebergs in motion or as pack ice formation pressure ridge existence,

depth and frequency, as well as the more familiar sea condition and weather parameters common to other regions of the world.

This independent specialized study of Canadian Arctic oil, is not based on operational data and is not therefore a case study. It is inclined in the generalization, for its documentation of the difficulties inherent in the oil prospecting and production projection, at this time and in this region, and to show an independent estimate of regional benefits.

The requirement to seek operational effectiveness in the ice environment clearly depends on the degree of compatibility and adaptability that operational equipment and procedures can provide as a result of appropriate knowledge of the time-varying characteristics of all forms of ice. Few of these characteristics are currently available on the scale that is necessary to comprehensive planning both of equipment design or selection and of the operations themselves. Operational costs are therefore difficult to predict and investment risk is great, factors which tend to constrain movement toward expansion of the development of the considerable Arctic resources estimated to be present.

The collection of environmental data and its reduction are a necessary preamble to the structuring of research, development and technique programs that will result in an optimum compatability and adaptability in the operating

environment of that which is needed to produce and transport the oil. When the equipment and operating procedures have been carefully selected, of necessity their effective functioning will depend on a variety of forecasting requirements related to the ice, the weather and the sea state.

The area of the regions involved is vast; consequently satellite observation is ideally suited to the task, although not exclusively so because of possible local limitation of satellite-borne instrumentations. Thus locally other observational sensors may be necessary, airborne or helicopter borne. All sensors must however be as close to all-weather operational as possible, and the weather involved is both fog and a wide range of precipitation densities, from light rain to heavy snow. Thus, there is a requirement for micro-wave frequency remote sensors such as those that SEASAT will provide.

Potentially, therefore, SEASAT can be very beneficial to Arctic offshore and coastal oil prospecting, providing data from which functional forms of compatible equipment and operations can be constructed and data which will minimize avoidable economic losses during operations with this equipment. Very importantly also, a systematic approach to exploiting the Arctic resources, which SEASAT can contribute to, can reduce the impact of Arctic operations on the natural environment, limiting ecological interference.

The case studies reported so far, based purely on sea located operations have only a tenuous relationship with Arctic operations. Arctic oil production was not explicitly evaluated and was implicitly subsumed under the heading of 'world rough' in modeling estimation. (p. 78)

The data in this study is specialized to the Canadian Arctic and the benefit estimates therefrom have been provided specifically by the Canada Centre for Remote Sensing, Ottawa, Ontario, Canada.

The study addresses activity on a regional basis; the Canadian East Coast, Beaufort Sea, Arctic Islands, Davis Strait-Baffin Bay and Hudson Bay and for each of these regions, where possible, benefits to remote sensing are developed, for different phases of oil production activities. Some suggested benefits arise, based on Arctic activity, before 1985 -- the earliest expected time for an operational SEASAT. The achievement of these benefits is therefore doubtful.

Because of the involvement of multinational corporations, and the complexities of contract work, it is not clear what portion of the benefits would be related directly to operations of Canadian companies. Nor is it clear whether the gross benefits to foreign companies would be reflected as Canadian benefits through adjusted prices, royalties, tax levies or government service charges.

6.8.1 Summary of Benefits

Benefits of remote sensing to Canadian Arctic offshore petroleum exploration and production are potentially large and estimates of the value of ideal ice and weather information have ranged up to ten percent of total costs. For those limited, more easily quantifiable benefit areas looked at, benefits from forecasting environmental conditions to daily operations tended to fall in the 3-4 percent range. It has been difficult to quantify many economic benefits however, because of speculation about technology to be used in the development and production phase and the general lack of experience to date in all phases of petroleum production activities in ice infested waters. The economic importance of scheduling can be expected to greatly increase as activities progress into the production phase. In the final analysis, benefits from remote sensing assisted improvements in ice and weather forecasting may be largest in promoting safe operations and reducing environmental damage. The risks to wildlife are great in areas such as the Beaufort Sea and in Lancaster Sound where drilling will be done in 2,500 feet of water.

Table 6.8 presents a summary of some of the economic benefits to the Canadian Arctic offshore petroleum industry. It shows potential gross benefits of \$31.2 million in 1981 rising to \$47.6 million in 1985 and decreasing to \$25.8 million in 1990. If only 50 percent of these benefits were

Table 6.8 Potential Gross Benefits of Remote Sensing Systems to Canadian Arctic Offshore Petroleum Production (All figures in $ millions)

	Offshore East Coast		Beaufort Sea			Arctic Islands Offshore		Baffin Bay - Davis Strait Offshore		
Year	Exploration Wells	Development Wells	Exploration Wells	Development Wells	Platforms and Pipelines	Exploration Wells	Development Wells	Exploration Wells	Development Wells	Total
1981	6.0		16.2-21.6			3.6		5.4		21.2-36.6
1985	2.4	9.9	7.2- 9.6	7.2	2.0-2.4	2.3	4.4	3.0	9.2	47.6-50.4
1990	1.2	6.8	3.6- 4.8	3.6	0.5	1.8	2.4	2.1	3.8	25.8-27.0

achieved in 1990 with a system including a SEASAT or equivalent operational satellite system, benefits of $12.9 to $13.5 million per year would result.

The current SEASAT planning does not envisage an operational SEASAT before 1985. For this reason, the benefits prior to 1985 shown in Table 6.9 are not included in the estimation of SEASAT benefits

The benefits to SEASAT from Arctic offshore oil operations are assumed to be $47.6 million in 1985, declining to $25.8 million in 1990.

Assuming that the benefits estimated decline linearly with time at a rate of $4.4 million per annum, there will be no benefits beyond 1995. The integrated undiscounted benefit from 1985 onward will then be about $282 million.

In the modeling procedure, from which a generalization was produced, the total annual unadjusted benefit derived was $657.7 million. (See 6.3, p. 75.)

Weighting this for weather, assuming world (rough) was an estimate for the Arctic regions. would allocate about 3 percent of this benefit to this region annually, i.e., about $18.7 million per annum from 1985 to 2000. Thus the integrated benefit from the model would be about $299 million, for the Arctic region in general rather than just for the Canadian Arctic.

Table 6.9 Integrated Benefits from Improved Ocean Weather Forecasts to Offshore Oil and Gas Industry Production and Exploratory Drilling (1985-2000)

Annual Discount rate	0%	5%	10%	15%
SEASAT exclusive benefit range $ million	464 - 2656	195 - 1113	87 - 501	43 - 244
SEASAT exclusive most likely benefit range $ million	1136 - 1824	476 - 765	214 - 344	104 - 168
Range of benefit from all forecasting sources $ million	1547 - 8853	650 - 3710	290 - 1670	143 - 813
Most likely range of benefits from all forecasting sources $ million	3787 - 6080	1587 - 2550	713 - 1147	347 - 560

It is possible that the model's allocation to world (rough) is not sufficiently large, yet both the Canadian estimates and the model's estimates are dependent on the conjectured oil production from the 'rough' regions of the world. This production must compete in the world markets with the production from world (smooth) which essentially appears capable of providing oil at much less overall investment cost.

The Canadian estimates and those from the model differ in the time period at which benefits will accrue to a satellite capable of providing the remote sensing data necessary for Arctic ice operations. Thus the Canadian discounted benefits will be higher than those from the model used in this generalization.

Overall however, considering the differences of approach and the considerable difficulties in projection of the regional distribution of offshore oil production, the two results are in reasonable agreement with respect to the expected undiscounted benefit, in a conservative manner.

6.8.2 Study Results

Benefits are developed and discussed on a regional basis according to available data and the regional peculiarities with respect to ice influences on different phases of offshore oil operations.

6.8.3 East Coast Offshore

6.8.3.1 Exploratory Drilling

Approximately $365 million has been spent on east coast offshore exploration. One hundred and six exploratory wells have been drilled to the end of 1974 in search of estimated reserves of 47.5 billion barrels of oil and 307 trillion cubic feet of gas.* Major focus of exploration interest has shifted from the Scotian shelf and Grand Banks where significant commercial discoveries have not been made and little action is expected in the near future (possibly one rig operating). The Labrador Sea, however, shows considerable promise particularly for gas. Impressive gas discoveries have been made here in two of three wildcats drilled by Eastcan in 1973 and 1974. Information is not adequate to make valid reserve estimates (although one partner published an estimate of 21 billion barrels of oil).** The total world fleet (three) of dypo self-positioning drillships are to be used here in the summer of 1975. These drillships cost $90,000 to $100,000 per day to operate.

6.8.3.2 Problems Encountered in Drilling Operations

The iceberg infested waters lying off Canada's east

*Oilweek, February 17, 1975, p. 49.

**Ibid., p. 74.

coast and covering her continental shelf from the Grand Banks north to Ellesmere Island present severe problems for the offshore petroleum industry. The problems are especially acute in the Labrador Sea and the constant danger of icebergs colliding with fixed installations diminishes almost at the same time as the weather gets too rough for drillships. This results in a short working season, extending from June when the Labrador pack ice breaks up to possibly mid-October when weather conditions become very bad.

There are numerous examples of operational delays caused by iceberg, weather or pack-ice threats. For example, in January 1973 a well was spudded 215 miles east of the Avalon Penninsula of Newfoundland. Ice moved in just after the well was spudded and the drilling rig had to be moved. The work had to be redone later at a loss of $200,000. Operations would not have been started had it been known that there was an ice threat in the area. Eastcan's Pelican and B.P.'s Havdrill, the two dynamically positioned vessels operating in the Labrador Sea in 1974, both experienced difficulties. "The Pelican spent 50 percent of its time off hole in October waiting for weather or dodging icebergs. It drilled and tested the successful Gudrid well, losing one of its main propellers to drift ice."* B.P.'s Havdrill "dodged bergs going south and

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*<u>Oilweek</u>, February 15, 1975, p. 74.

would often dodge the same bergs going north the following day." A total of 12.6 days were spent in 1974 waiting because of ice and weather. When the ship left in the fall, it had left its BOP (blow off preventer) stack and 8,000 feet of drillpipe on the seafloor as a result of a storm.* This problem cost B.P. about $2 million in rig damage and work lost in 1974. The Havdrill is scheduled to return earily (June 15) to finish the well. The company is prepared to spend two weeks to repair damage and get back on the well making a probable total loss of $3-$4 million. Already the well has cost $8 million and <u>this one problem could cost more than ten percent of total expenditures to date for the four wells drilled in this area</u>.

These examples illustrate the environmental problems faced in this offshore area. Icebergs almost prohibit the use of conventional anchored semisubmersibles which are more stable and could work later in the season--"An Eastcan official speculated if a semi had been on the job last year, it would have been constantly disconnected except toward the end of October when it could have continued while rough weather chased the floaters away"** (Ref. 5).

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*Ibid., December 16, 1975, p. 59.

**Ibid., February 17, 1975, p. 74.

While the dynamically positioned ships have berg-tracking radar on board and can disconnect in a few minutes, they may still require air reconnaissance information on bergs during certain critical periods when iceberg-free "time windows" and calm sea conditions are required to carry out certain operations. These periods include the initial drilling period, a period when the crew are running casing to protect the well, and the flow-testing period. Iceberg-free conditions required may be one to three days depending on the operation.

Pack ice in the open sea in many ways is a more formidable problem than icebergs and when both icebergs and pack ice are present, operations may be impossible. Pack-ice surveillance is important particularly at the beginning of the season and will become more important at the end if rigs are designed to cope with fall weather conditions. Any extension of the short drilling season would have economic value.

Sea state and weather forecasts are essential throughout the drilling season and become especially critical in the fall. There are examples of operational shutdowns because of storm forecasts which did not materialize or did not as early or to the degree anticipated. Rig operators generally operate conservatively. Examples were found of

unnecessary delays up to three days because of forecasted impending high winds and waves which did not materialize. For example, a rig might disconnect fearing wave heights would get dangerous but although they didn't, the sea was too rough for repositioning which requires calm waters. On the other hand there are examples such as that of the Hav-drill mentioned above, when either sufficient warning is not given or operators do not have sufficient faith in the fore-cast. General weather forecasts are received from shore sta-tions 100 or more miles away and these may be quite inaccur-ate as to local conditions.

The east coast region is cloud covered most of the time with frequent dense fog. These conditions make micro-wave sensing essential. The iceberg-tracking radars (range 16-18 mile) on board the rigs have helped considerably, al-though difficulties are still experienced detecting some bergs, particularly growlers and bergs of certain geometries which become lost in the sea clutter. (Amoco has not been as successful using these radars in local surveillance as B.P. and Eastcan.)

6.8.3.3 Data Requirements

The most severe new problem encountered by off-shore drilling crews is icebergs. The detailed drift patterns of icebergs have not received much attention and now become extremely important to fixed operations. Iceberg motion is related to wind, wind driven currents, and changes in

6.8.3.4 Remote Sensing Benefits

Remote sensing providing all-weather reconnaissance of ice and icebergs, wave heights, surface winds and temperatures may provide benefits to offshore drilling operations in the following ways:

1. Extension of season

Benefits may be obtained at both the beginning and end of the season. Historical data is particularly valuable here. For example, the Havdrill is to arrive on the Labrador coast June 15, 1975 and B.P. expects the Pelican to start drilling the first half of July and the Sedco 445 in the second half.* Historical data on ice, wave and weather which is limited at the moment could help in determining in what locations drilling can start earlier, and what is the likely optimum time for a given location.

A very significant prolonging of the season into the fall is probable but environmental data is extremely limited during this rough water period. Information on wave heights and winds is needed. For example, Eastcan representatives have indicated that the season in the Labrador Sea could possibly be extended from mid-October into December but "nobody knows the weather". Benefits would arise from fixed costs, e.g., mobilization and demobilization, spread over a longer working season. Consider extension of a season by one month, e.g., from

*Globe and Mail, April 17, 1975, p. B-14.

90 days to 120 days. A fixed cost of $1 million is probable. (This is variable depending on where the rig and supply vessels, iceberg towing vessels, helicopters, etc. have to be moved from.) Spreading these fixed costs over the extended season would result in a benefit of $330,000.

A much shorter extension of season (perhaps only two to three days) might make the difference of completion of a well or having to return to it at the beginning of the following year. This is particularly true in the Labrador Sea area where "approximately" two wells may be drilled in a three to four month period, but the second may not quite be completed. The benefit here could be one to two days operating time or approximately $100,000 to $200,000. Of the four wells drilled in this area for example, the Havdrill will return to complete Bonaventure in 1975 and the Pelican in 1974 returned to test the Bjarni well drilled in 1973.

Without statistical data on ice conditions built up over several years, there is also the possibility of bringing in a rig before it is possible to start drilling. In 1974 the Havdrill had to wait three days for pack ice to clear before it could start operations. A rig sitting idle for one week would cost about $400,000. (Although conditions in ice-infested waters can change from year to year, clearly environmental and economic benefits will result from baseline

data collected throughout these offshore areas, including many areas in which the possibility of substantial future activity appears remote at the moment.)

An extended reliable weather forecast could have significant benefits near the end of the season. For example, a decision to cease operations rather than wait could result from a forecast which indicated weather would be unfavorable for operations for at least four or five days. As experimental modeling using SEASAT-type data is now being done, such forecasts may become possible. A saving of $400,000 would result in the above illustration, assuming the decision to cease the season's operations would otherwise just be delayed.

2. Wildcat drilling site location may be affected by historical data on ice, icebergs, weather and waves. Where other factors are equal it is probable there are areas more suitable than others where iceberg encroachment, for example, may be slightly less probable. While this data certainly would not affect location of all wells, it could be very beneficial for possibly one out of four wells, resulting in savings of one to two days or $25,000 to $50,000 on average per well.

3. Substantial benefits can be expected from daily reconnaissance and forecasting of ice, iceberg and wave conditions. Iceberg reconnaissance will be particularly

important in choosing the iceberg-free "windows" discussed earlier. Fog or storms may make it difficult with other than microwave remote sensing. Frequent surveillance gives information on how fast ice is forming and drifting and how icebergs are drifting permitting a long lead time for ongoing or better planning. Such reconnaissance on an on-going basis combined with on-site observations will optimize operational efficiency. An average saving per well of 12-24 hours in this area due to improved ice and iceberg surveillance and one to two days due to improved wave and weather forecasts is probable. This amounts to $150-$300 thousand per well. (An Amoco official felt that two-days saving per hold for iceberg reconnaissance, only even with current on-site radar, was very conservative.) B.P. officials indicated they have had good success in iceberg-infested areas with their quick release capability and on-site radar, helicopter and tow ship. Forecast of a rough sea causing a ship to pull its marine riser system <u>may force a wait of perhaps three days or even a week till the sea becomes very calm for repositioning</u>. This could represent a large loss if a hazardous sea state did not develop because drilling can continue in sea states much rougher than the calm waters required for repositioning.

4. Design optimization benefits may also result. For example, drilling in the deeper water area off Labrador is

expected in the late 1970s or early 1980s and questions of mobility (because of icebergs) and stability (because of sea state) must be answered.

5. Benefits may result from reduced damage to drill-ships. The Pelican cost $50 million to build and dypo (dynamically positioned) ships currently building come close to $80 million.* Without accurate prediction of impending high wave and wind conditions and iceberg drift, not only will unnecessary movements off-site take place, but also the possibility of failure to move when necessary arises. Insurance rates are high in an environment more hostile than the North Sea. Here, during the winter months of 1973 alone, (about 30 rigs operating) insurance reimbursement of $35 million in damages was paid. This covered the total loss of one large rig and repairs resulting from substantial wind damage to other drilling structures.**

The safe conduct of marine resupply operations is dependent on good wave, weather and ice information. Storm and fog information is essential for helicopter operations.

Freezing spray forecasting required by both supply vessels and rigs may be improved using remote sensing data which provides sea state, surface winds and temperature

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*Oilweek, February 17, 1975, p. 76.

**ECON, Inc., SEASAT Economic Assessment, October 1974, p. 8-8.

data. There will be no spray-induced icing where there is heavy pack ice.*

6. Environmental data, both real time and historical, would reduce duplication of data gathering by petroleum companies which, due to competitiveness, may not fully share data.

Companies are faced with the problem of exploring a huge block of permits in a limited period. Improved environmental data will mean that they can do this more safely and will not have to "cut expensive corners" to meet permit time constraints.

It is important to note that benefits of improved information from remotely sensed data occur in a variety of ways and not all of those indicated would apply or be realized for a particular well. Moreover the principal areas of benefits can be expected to change with technology advances and lengthening of the working season. (This is already evident with the dynamically positioned ships currently handling the iceberg problem much better than was the case for the first east coast offshore drilling.) Currently, exploratory drilling is done only during the ideal summer period. If the initial successes in the Labrador Sea continue, it is probable companies will attempt to extend the season.

*Energy Communications, Inc., "Arctic Offshore Problems Examined," Offshore Technology Yearbook, 1974.

Technology advances will be made, e.g. dynamically positioned semisubmersibles which can withstand high waves and winds, will probably be available in several years.* (The daily operating cost can be expected to increase.) In spite of these advances, as the working season is pushed into the more unpredictable and more hazardous storm and pack-ice seasons, the need for excellent reconnaissance and forecasting can be expected to increase rather than diminish.

Adding up the benefits given above, the saving per well due to reliable ice surveillance and weather forecasting and the collection of baseline data amounts to about $200,000 - $400,000 per exploratory well or on average about 4 percent of the well cost. (This is considered conservative taking into account opinions ranging to ten percent mentioned earlier and considering incidents such as the 1974 Havdrill experience costing about ten percent of total costs for four Labrador Sea wells drilled to date.) Benefits would come from such areas as reduction of "false alarms" causing pulling of the marine riser system and accidents due to sudden storms.

Although the schedule for well drilling is highly uncertain and depends on many factors including success rate, petroleum production estimates supplied by one company suggest that possibly a maximum of 20 per year will be reached by 1981 and decrease thereafter to about six per year by 1986 and four per year by 1990.

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*Oilweek, February 17, 1975, p. 49.

Remote sensing benefits to east coast exploratory drilling could therefore, in theory, rise to a maximum of \$6 million in 1981 if optimum data collection systems and appropriate communications systems and weather forecasting models were in place, dropping thereafter to about \$1.8 million in 1986 and decreasing thereafter. No attempt will be made to forecast what percentage of this is realizable, as several factors and systems are involved. With appropriate systems in place, it is estimated that SEASAT or equivalent microwave sensing operational systems could provide a gross benefit of \$600,000 in 1990.

6.8.3.5 Development and Production Phase

Although technical problems because of environmental conditions are bad in the exploratory drilling phase, they become more severe in the development and production phase. During this phase the level of activity increases considerably. Instead of a few rigs drilling wildcat wells during the best weather period, considerably expanded drilling activity will take place, as well as construction of gathering and processing plants, oil storage and tanker terminals and either seabed gas pipelines or an LNG terminal. Work will be carried out in an extended season and ice and weather surveillance

and prediction must be excellent to maximize the length of the operating season and daily operating efficiency.

The production phase is by far the most expensive--more than 86 percent of the total expenditure in an example by Cazenove and Company.*

The solution to environmental hazards in the exploratory phase has been dynamically positioned drillships with automatic pipe handling which may get off the well quickly. Since fixed structures are unlikely in the Labrador Sea, a similar type of vessel will likely be used in development drilling. The cost per well may be slightly less than for exploratory, i.e., probably 50 days x $100,000.

The desire to have a long operating season may result in sacrificing something in time required to <u>disconnect</u> for more stability in handling fall storm conditions.

Anchored semisubmersibles would require about one-day warning of a potential problem and would require one to two days to get back on the well and set the anchors. Development of dynamically positioned semisubmersibles is being considered, as mentioned previously.

Ice-breaking type vessels are also being considered which could stand up to some ice and would double the operating season.** The operating cost would also double to about $200,000 per day. Icebergs and heavy seas would still cause shutdown or disconnect from the well.

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* Cazenove & Company, "The Search for Oil and Gas and the Implications for Investment," London, 1972, p. 49.

**<u>Oilweek</u>, February 17, 1975, p. 76.

This system could require one-half to two days to get back into operation after disconnecting, depending on whether it was anchored or self-positioning. It is possible that a self-propelled production platform will be used with ability to maintain its position until threatened by an untowable iceberg (more than 1 million tons) or heavy pack ice and then move off (protective structures such as a network of wires anchored to the seabed may also reduce frequency of disconnect). Generally iceberg hazards may be handled by deflecting the berg away from installations, designing the installations to withstand possible impacts or to move out of the path, or locating the operation in a safe place.)

In view of accessibility of oil tankers to the area and the potential threat of iceberg scouring to seabed pipelines, a floating storage vessel costing possibly $50 million either anchored or self-positioned is probable and would cast off under severe ice or iceberg threat. Historical data will help in determining the optimum system, how fast it must move off, etc.

6.8.3.6 Remote Sensing Benefits

In spite of improved and developing technology, similar types of benefits from remotely sensed data can be expected in the development drilling phase as in the exploratory phase.

These will include making use of an optimum length of working season and reducing unproductive time by good ice and sea state surveillance and forecasting. This data becomes critical outside the fair weather period. Savings per well for unproductive days (one and one-half to three days) of $150,000 to $300,000 are estimated with pack-ice surveillance assuming a greater importance than before (because of the extended season). Weather forecasts become more important for resupply operations in this extended season

Historical data on iceberg statistics in a given location can affect the concept of the production system. If a floating storage system is used, this data would provide information as to the frequency and speed with which the vessel would have to move out of the way and what defense structures would be required. A difference in design cost (possibly as much as five to ten percent or $2.5 to $5 million on a $50 million structure) could result. The same information is vital for sea bottom pipeline gathering systems where scouring hazards exist and a ruptured line from a single well could result in loss of production of 10,000 barrels a day or $25,000 of oil per day for possibly two weeks.

A seabed facility will have to be protected from the iceberg scouring hazard while a surface storage facility will have the pack ice as its major problem. If a storage facility

has to be moved frequently, continuity of supply may be affected. The safety of transfer of oil from a storage vessel to a tanker depends on environmental conditions which must be monitored and forecasted. Clearly excellent data is required, both historical for design and reconnaissance for operations, to avoid severe environmental and economic penalties. It is assumed that development drilling will commence in 1982, subject to government approval, and that construction of gathering systems, processing plants, storage and tanker terminals will take place in the 1982-1986 timeframe.

Using (perhaps optimistic) production estimates of 1.05 million barrels of oil per day and 2,800 million cubic feet per day of gas by 1990, it is estimated that gas and oil development drilling will increase to a maximum of 44 wells drilled in 1984 and decrease thereafter to 30 in 1990.

Remote sensing benefits of $150,000 to $300,000 per well or, on average, $225,000 would, in theory, give benefits of $6.3 million in 1982 rising to $9.9 million in 1984, dropping to about $6.8 million in 1990 and thereafter decreasing. An operational SEASAT or equivalent system with ancillary communication systems and models in place is estimated to achieve 50 percent of these benefits by 1990.

The benefits given above do not include other production phase benefits including weather and ice information

during construction of gathering and processing plants, storage facilities, pipelines and tanker terminals. Also not included are benefits, both economic and safety, to resupply operations and to design of structures and scheduling.

6.8.4 Beaufort Sea

6.8.4.1 Exploratory Drilling

Exploratory drilling in the Mackenzie Delta offshore area has been from artificial islands. Imperial Oil has had oil strikes at Imik and Adgo. The first step out on Imperial's Adgo field has been a success, and industry speculation has the field potential in the 750 million barrel category.* Exploratory drilling will commence in the Beaufort Sea in 1976 where a $5 million environmental study was started in 1974 (and is being continued in 1975) and reserve estimates have been given as ten billion barrels of oil and 75 trillion cubic feet of gas.** First plans were to move two specially designed floating drillships into the Beaufort area during the 1975 navigation season and to winter them there so the permitted drilling project could begin early in the open water season of 1976. Because of construction delays, the ships are to be brought around Point Barrow as soon as ice conditions permit in 1976.***

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*Oilweek, April 14, 1975, p. 5.

**Ibid., February 3, 1975, p. 9.

***"Canmar Plans Summar Environment Program," The Beaufort Seer, April 1975.

6.8.4.2 Problems Encountered in Exploratory Drilling

The environmental problems associated with offshore activity in the Beaufort Sea are much different from those on the east coast offshore and therefore require different information. The drilling season is so short that offshore rigs will not likely move to other locations. This is unlike the east coast rigs which go to the North Sea or other locations when weather prohibits operations in Canadian waters. The drilling costs may, therefore, be more than three times those on the east coast because of standby costs of up to nine months.

Different structures are required governed by platform mobility requirements and cost considerations which, in turn, are a function of water depth and related ice conditions.* Ice conditions such as movement and pressure ridges become more important in deeper water.

In the Beaufort Sea the Arctic Pack usually recedes during the summer (July to September) to a distance of 80 to 150 miles offshore. (In Extreme conditions such as 1974, this distance may be considerably smaller.) This pack is made up of multiyear ice which can reach a thickness greater than 50 feet.** The nearshore areas are essentially ice-free during the summer months but <u>may be invaded at any time by ice floes from the Arctic Ice Pack</u>. Strong winds with gusts up to 70 mph are common.

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*R. Voelker and C. Schultz, Energy Communications, Inc., "The Battle Against Ice Begins," Offshore Technology Yearbook, 1974.

**J.G. Riley, Energy Communications, Inc., "How Imperial Built the First Arctic Island," Offshore Technology Yearbook, 1974, p. 6.

An indication of the difficulties associated with offshore construction is given by considering the construction of the Immerk artificial island used as a base for offshore drilling. The start of dredging operations was restricted to July 15, 1972 because of concern for the Beluga whale migration. Construction efforts were seriously delayed by dense fog and invasion of the work area by massive ice floes. Attempts to carry out dredging operations in adverse sea conditions resulted in considerable damage to the dredge. "Of the 70 potential working days from July 15 to September 22, actual placement of material on the island occupied only 27 days."*

6.8.4.3 Remote Sensing Benefits

Two exploratory wells will be drilled in the Beaufort Sea in 1976. The original plan called for these rigs to winter in the Arctic so that as long a drilling season as ice conditions permit could be used. It is expected that these wells will cost $25 million each and that the daily operating cost will be $300,000 to $350,000 because of the short (three month) working season (and lengthy standby time). The large benefits of ice reconnaissance are immediately apparent. A radar system will be on the site, but aerial coverage will be needed to tell the extent and nature of the encroaching ice. If a large floe of

*J.R. Riley, Energy Communications, Inc., "How Imperial Built the First Arctic Island," Offshore Technology Yearbook, 1974, p. 6.

multiyear ice encroaches on the site, moving will be required. In this region the Arctic pack advances and retreats, and it is necessary to have a detailed daily surveillance of its position, rate of movement, nature of pack, etc., so that operations may be started as early as possible in the season and rigs can operate to close tolerances as to when to shut down or move. All-weather reconnaissance is required (helicopters may be frequently grounded by heavy fog or storm conditions).

Estimates of the value of all-weather ice reconnaissance and reliable 48-hour weather forecasting range up to two-weeks saving in time per drilling season particularly in a year when there is frequent movement of the ice. A saving of three to four days per well in total is, therefore, considered conservative. This could result in several ways. Twice daily microwave ice reconnaissance at the beginning of the season could result in an earlier start of one to two days. The favorable conditions could otherwise be missed because of severe fog grounding helicopters. As discussed earlier, daily surveillance could avert unnecessary shutting down or moving off well completely. The ships to be used in 1976 are anchored. This means that unnecessary moving off, returning and resetting anchors would lose a minimum of two days in calm seas and could lose a week or more if the sea was not calm enough to permit repositioning the marine riser.

Surface wind information and reliable 48-hour weather forecasts predicting winds that could drive ice away from or toward fixed installations would have large benefits--in the former case, giving confidence to continue operations and, in the latter, possibly, preventing a disaster including damage to a $50-80 million rig. Appropriate ice reconnaissance and weather forecasting permitting an extension of the season by only one to two days could result in completion of the well, making unnecessary a return to that well the following year, and a net timesaving of possibly one or two days. Resupply operations both by ship and helicopter can be scheduled and carried out more efficiently and safely with ice and wave reconnaissance. A reliable 48-hour weather forecast would be particularly beneficial for these operations. A three-to-four day saving per well represents $0.9 - $1.2 million at an effective rate of $300,000 per day. This represents about 3.6 percent to 4.8 percent of the estimated well cost. Assuming production estimates for oil of 500,000 billion barrels per day by 1987 and 650,000 billion barrels per day by 1990, a reasonable exploratory well drilling schedule would see the number of wells per year increasing to about 18 by 1981 and decreasing thereafter to four in 1990. Applying the above estimates results in benefits reaching a maximum of $16.2-$21.6 million in 1981 and decreasing thereafter to a value of about

$3.6 to $4.8 million in 1990. (As before, these assume appropriate remote sensing data acquisition systems, communication systems and forecasting models in place.) Operational SEASAT (or equivalent) data input into a suitable information system could be expected to yield 50% of these benefits by 1990.

6.8.4.4 Development and Production

Benefits of remote sensing in these latter phases are uncertain until the nature of structures to be used is decided upon. However, remote sensing data can provide some of the information on ice characteristics such as movement and pressure ridges which can help decide on optimum structures to be used, both from an economic and environmental viewpoint.

It is probable that in shallower water a permanent platform will be used to directionally drill eight to thirty wells. In water up to 30', man-made islands will likely continue to be used and from 30' to 120', cone shaped bottom founded structures are probable. Seafloor pipelines may then be laid to shore or to offshore tanker berths. In deeper water, in part because of cost and pack ice pressures, development drilling may be done from floating vessels which move off under unfavorable conditions. Subsea completion techniques will likely be used in deeper water areas.*

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*Reference 18.

If development drilling is done from floating vessels, the need for constant ice surveillance and weather and wave information is critical for operations. If it is done from a fixed platform, erection of that platform and movement of equipment to the location are very sensitive to environmental factors, and subsequent drilling becomes less sensitive. In both cases, design criteria are strongly affected by historical environmental data and several percentages of the capital cost could be saved by good data to assist design. For development drilling done from floating vessels, the same types of benefits from ice and weather information apply as for exploratory drilling. Because the time required for development drilling is slightly less, and there is likely to be a greater concentration of activity in the area, the benefits per well from remote sensing ice surveillance and weather forecasting are likely to be slightly less than in the exploratory phase. A two-day overall saving is probable with reduction of "false alarms" and working to close tolerances in a hostile environment, the major benefit.

Possibly 50 percent of development drilling will be done from fixed platforms, with at least eight directional wells drilled from each. Assessing benefits from ice and weather forecasting in this case is very difficult.

The Battelle researchers have considered potential benefits from SEASAT data by considering a specific case - that of a three-platform oil production operation in the North Sea.* By examining the project log, they found that out of 26 days that two derrick barges were committed to the task of lifting the main production platform deck onto the legs, 11 days were spent holding or towing due to weather conditions. They conclude that 22/52 or 42.3 percent of derrick barge days could have been saved by a reliable 48-hour sea state forecast provided using operational SEASAT data. For this project, the benefits would come from reducible labor charges and would amount to 22 operating days at $25,000 per day or $550,000.

While benefits such as that listed above can be expected to apply in the Beaufort Sea, the installation timing of the platform is likely to be of much more importance in this area. The platform supports the entire drilling and producting operation and is, therefore, the most important single item. The short open-water season means that timing is critical to avoid waiting a full year for another installation period. An indication of the importance of platform installation timing to the entire project has been given by Culver for the Gulf of Mexico in an area where current technology for platform design exists and the conceptual design problems encountered in deep water areas,

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*ECON, Inc., SEASAT Economic Assessment, October 1974, p. 8-8.

extreme weather areas, ice flow and iceberg areas do not apply. "In order to continue safe operations in this hostile marine environment and do so at a profit, factors that eventually will shape the financial outcome of a project must be forecast as accurately as possible--the most formidable factor to accurate cost predictions in offshore work is the natural elements of the environment. The wind, waves and weather are adversities that must be considered. Detailed time studies must be conducted to insure that all facets of the platform installation work can be accomplished during good weather which generally runs from May through September. This is true despite the fact that this is also the hurricane season. Often times, it is necessary to pay a premium during the design or fabrication stage to accelerate work so that platform installations will occur during favorable weather. Failure to take notice of or to make allowance for this potential pitfall may result in the actual platform installation cost being higher by 50 to 200 percent compared to the original estimate."*

The same considerations apply in ice-infested waters but with much more severe timing restrictions. In a bad ice year when the ice retreats only for a short time or when it advances and retreats several times, it may take every available day to complete the installation. Excellent ice and weather forecasting become imperative. The operations of

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* Energy Communications, Inc., "Forecasting Offshore Platform Development Costs," Offshore Technology Yearbook, 1974, p. 182.

mobilization and movement of the platform and support equipment to the site and platform installation are all ice and weather sensitive. An indication of the sensitivity of the operation of platform deck installation in the example given above for the North Sea is obtained by noting that six of the 11 days spent waiting were days during which pipe was laid. For the structures expected to be used in the Beaufort Sea, encroaching ice will present the major problem. In an area where fog frequently grounds helicopters, a rigid schedule will likely have to be followed to transport the bottom founded structure, right it into position and secure it, install drilling rigs on top, bring in production equipment, etc. A permanent platform will cost more than $50 million. Installation costs of at least 10 percent can be expected (The Science Council in cost estimates for an east coast platform give installation costs at about one-third.* Considering the Battelle study, experience in the Gulf of Mexico, and the more critical timing conditions in the Arctic, benefits from ice and weather forecasting ranging from $0.55 million (the value for the North Sea considered as a lower limit) to several million in this area are probable. Once development drilling from platforms commences, benefits of ice and weather forecasting will be mainly to resupply operations. Substantial losses (about $100,000) could be

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*"A Case Study of East Coast Offshore Petroleum Explorations," Science Council of Canada Background Study, No. 30, p. 101.

expected if a rig were to sit idle for a day waiting for supply. A reliable 48-hour weather forecast would allow proper scheduling of resupplies.

A scenario for development drilling giving oil production of 0.5 million barrels per day by 1987 and 650,000 barrels per day by 1990 and gas production of 200 million cubic feet per day in 1987 and 2,800 million cubic feet per day in 1990 would be 35 gas and oil wells drilled in 1982 decreasing to 17 in 1990. Assuming 50 percent of the wells are drilled from permanent platforms and the remainder from drillships, approximately one platform would be installed per year beginning in 1982 from which 17 wells are drilled. The remaining 18 wells per year are drilled from floating vessels with savings of two days each at $200,000 per day or $7.2 million in 1982, and decreasing after 1985 to $3.6 million in 1990. Remote sensing assisted benefits to development drilling when platforms are used are conservatively put at $0.55 to $1 million per year beginning in 1982. Input of SEASAT or equivalent microwave sensor data into appropriate systems is again estimated at 50 percent or $2.6 million in 1990.

Pipelaying is one of the costliest items in bringing an offshore oil field into production. Installation costs are high and represent 75 percent of the total

pipeline cost as an estimate.* In ice-infested areas this percentage could be even higher.

The offshore pipeline laying phase will be extremely dependent on environmental conditions. Pipelines are possible in the Beaufort Sea, (and may be necessary because of the pack ice) but there are two problems. The pipe must be protected from scouring from ice islands which ground on the bottom. This would involve dredging. Also, the pipeline carrying hot oil may have to be insulated if there are seabed permafrost areas. A possible pipelaying spread would include a large barge, a burial barge, ten supply boats and four to five work boats to push the ice away.

Ice will present the most severe logistical problem for pipeline laying, but the rate at which it is laid is also dependent on sea state. The pipelaying barge must keep the pipe under tension to prevent buckling. If ice encroaches and cannot be handled by ships designed to break or push it away or if a severe storm is forecast, the pipe would have to be tied off and lowered to the ocean floor while maintaining tension. About one-third to one-half a day is likely to be required for the lowering operation and about one-half a day to resume operations when conditions permit.

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*Cazenove & Company, "The Search for Oil and Gas and the Implications for Investment," London, 1972, p. 49.

The Batelle studies have made benefit estimates of SEASAT data in the pipeline-laying phase by considering accident avoidance and avoidance of pipelaying barge costs for one North Sea project.* They found that 11 out of 272 days or four percent lost due to weather related accidents could have been saved by a reliable two-day weather forecast. The accidents were to the stinger or pipe support pontoon when the weather deteriorated so quickly that the pipe could not be released and the stinger retrieved satisfactorily. They found a saving of $87,500 per day or $962,000 for 11 days.

They also found that of 272 working days for the pipelaying barge, there were 64 or 23.5 percent for which there would have been a labor charge saving based on a reliable 48-hour forecast. These were periods when crews were kept holding waiting for weather to improve. A reliable 48-hour forecast would have saved 64 x 25,000 = $1.6 million.

The daily rate for barges, ancillary equipment and crews for pipeline laying in the Beaufort Sea is likely to be $200,000 or more per spread per day as compared with $100,000 in the North Sea, because of the short working season and extensive equipment standby costs. It is difficult to extrapolate from the North Sea to the Beaufort Sea because ice replaces sea state as the main environmental problem.

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*Econ, Inc., <u>SEASAT Economic Assessment</u>, October 1974, p. 8-8.

Remote sensing benefit estimates are highly speculative because of lack of operating experience under such conditions.

A value of three percent, more conservative than the four percent given above, for weather related accidents is likely to be appropriate in this hostile environment and would represent three days or about $600,000 in a 100-day working season. Much of this would be due to wind driven ice encroaching rapidly on the lay barge under fog or sudden storm conditions. However, a further four percent or four-days saving per season is probable from a variety of other benefit aspects of improved ice reconnaissance and weather forecasting. This includes reducing the number of false alarms and working to closer tolerances within the environment, e.g. not disconnecting the pipe and lowering it to the ocean floor when unnecessary. This procedure costs about one day in total time plus the time spent waiting for a storm to materialize or ice to move in which may be one to two days. It includes working in dense fog and fairly heavy sea state if the crew have the confidence that conditions will not deteriorate and there are no ice hazards. An extra working day or more might also be gained at the beginning or end of the season.

The potential time savings indicated above add up to a total of one week out of 100 days (considered conservative by some who felt that ten days was possible). These potential benefits total $1.4 million per spread per season.

The problems associated with dredging in this area have been clearly outlined in the description of the Immerk Island construction.* The problems they experienced with dense fog, ice floe invasion, strong winds and rough seas and damage to the dredge leading to prolonged standby periods (59 percent in September) can be expected to apply in the weather sensitive pipeline-laying phase. The benefits of $1.4 million per spread indicated above could be expected to occur in one or two seasons. Companies would probably gear up to complete a major line in a season if possible. Again, timing could be a critical factor with good forecasting, allowing a more efficient operation and higher probability of completing a line in a given season without waiting a full year. It is unlikely pipe can be laid off ice in winter particularly in the deeper water areas where it is continually moving. (In one month in the winter of 1975 beyond the 60-foot water level, the ice moved 60 miles.) Forecasting which helped in having a line completed in a given year could free equipment to work elsewhere, possibly reducing or eliminating standby costs of several thousand dollars daily during winter. Also, benefits could result if production were not delayed a year. Calculation of these benefits, which could be millions of dollars depends on how the

*J.R. Riley, "Energy Communication, Inc., "How Imperial Built the First Arctic Island," <u>Offshore Technology Yearbook</u>, 1974, p. 6.

petroleum production schedule was to be integrated into the national supply schedule.

It is assumed that pipelaying activities are carried out in two seasons for total calculable benefits of $2.8 million. These benefits are very conservative in view of considerations mentioned above.

6.8.5 Arctic Islands

Two offshore wells have been drilled during the winter from reinforced ice platforms by Panarctic. In 1977 an offshore well is to be drilled from a dynamically positioned drillship in Lancaster Sound in an area with a 90 to 120-day open season. Pack ice and ice islands present the main problems in the Arctic Islands, and good ice reconnaissance similar to the requirements for the Beaufort Sea is needed. (Some icebergs may also drift into Lancaster Sound.)

Development drilling will require a platform that can move off location under threat of heavy pack ice of ice islands (also icebergs in the Lancaster Sound area). An ice cutting semisubmersible is probable in the Arctic Island areas. During ice breakup conditions, the pack can move rapidly up to 30 miles per day. In spite of an ice cutting capability, these vessels could not cope with the ice and would have to move off.

Icebreakers or a rotary cutter may be used to chip away at the pack ice. Clearly, design is critically dependent on rate of ice movement and thickness and frequency

of pressure ridges. For example, assuming an icebreaking bow could be put on a rig, questions such as "Should it be designed to cut pressure ridges greater than 50 feet in thickness which may occur infrequently, or is it cheaper to move off for infrequent events?", must be answered.* Correct answers may be worth $10 million in construction cost or several million dollars in lost drilling time. (These vessels are expected to cost more than $100 million. Increasing the power of the ice-cutting element to handle worst possible ice thicknesses could cost up to $10 million.) It is probable a sea floor central gathering system will be used below the scour depth with storage onshore. Pipelaying will be required.

Water depths can be considerable throughout the Arctic Island Offshore areas and, for example, are about 2,000 to 2,500 feet in Lancaster Sound. Technology advances must be made for the development and production stage.

A possible scenario for petroleum production is 250,000 barrels of oil per day by 1990 and 2,600 million cubic feet of gas per day by 1990. Estimates of start of oil production range from 1985 to 1990. The offshore drilling activity could result in eight exploration wells per year by 1981, decreasing to four by 1990 and 22 development wells in 1985, decreasing to 11 in 1990. It is possible that

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*Oilweek, February 17, 1975, p. 76.

about half of the wells (both exploratory and development) will be drilled from ice platforms (as has been the case to date) and half from offshore systems as described above. Ice platforms would be used in shorefast ice areas, provided ice movement was very small.

The benefit areas considered for the Beaufort Sea generally apply to the Arctic Islands for those wells drilled in the moving ice. This can be expected to result in savings of approximately three days or $900,000 in the exploratory phase and two days or $400,000 in the development drilling phase for these wells. This would give benefits for exploratory drilling of $3.6 million in 1981 and $1.8 million in 1990 and for development drilling of $4.4 million in 1985 and $2.4 million in 1990. It is expected that pipelines will be laid off ice in winter in most of these areas. Benefits of remote sensing data in these areas has been considered previously.*

Although offshore drilling in the Islands has thus far been limited, successes to date indicate that considerable future activity is probable. Early in 1975, Panarctic drilled a successful stepout well to its Drake Point gas field discovery from a reinforced ice platform.

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*A.K. McQuillan and D.J. Clough, "Benefit of Remote Sensing of Sea Ice," Research Report No. 73-3, December, 1973.

The Panarctic president has been quoted as saying, "There is every indication the Drake Point field continues on and on out to sea",* The proven reserves of this field (more than five trillion cubic feet) make it the largest gas field ever found in Canada.

6.8.6 Davis Strait - Baffin Bay

Environmental conditions for offshore oil production in these areas have strong similarities to the Labrador Sea. Icebergs are massive and numerous, pack-ice problems exist, and heavy seas are common. Similar economic benefit considerations as those in the Labrador Sea may be applied.

Calculations similar to those in Section 6.2 yield benefits in the exploratory drilling phase of $5.4 million in 1981 decreasing to $2.1 million in 1990 and in the development phase of $9.2 million in 1982 and $3.8 million in 1990.

6.8.7 Hudson Bay

Two wells were drilled in Hudson Bay in 1974 by a Pentagone semisubmersible.** It is worth noting some of the weather and ice related experiences of this stable rig since it made history as the northernmost semisubmersible

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*"Panarctic Proves up Drake Point Reserves," Globe and Trail, May 8, 1975.

**Pentagone Semisubmersible was Idea for Short, Stormy Hudson Bay Season," Oilweek, December 16, 1974, p. 57.

operating in the world. In spite of its stability, it experienced delays due to "false alarms"--"Weather forecasts were for worse conditions so drilling was stopped on the Narwhal hole but it turned out that had not been necessary." It is also sustained some ice damage--"at one point ice floes began overtaking the rig from the rear and the pontoon was dented over a two square meter area". The semi-submersible lost a great amount of time in anchoring - enough to make the difference between three instead of two holes drilled in the 1974 open water season.

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